DAYTON PUBLIC LIBRARY
REFERENCE
2nd FLOOR

MONTHLY 7/6

The Journal of
THE ROYAL AERONAUTICAL SOCIETY

CONTENTS AUGUST 1950

DESIGN FOR MAINTENANCE
R. E. BISHOP, C.B.E., F.R.Ae.S.

THE BERLIN AIR LIFT
AIR COMMODORE J. W. F. MERER, C.B.

THE DRAG EFFECTS OF ROUGHNESS AT HIGH SUB-CRITICAL SPEEDS *A. D. YOUNG, M.A., A.F.R.Ae.S.*

SITING OF LANDING STRIPS FOR INTERNATIONAL AIRCRAFT MOVEMENTS IN GREAT BRITAIN
WILLIAM COURTENAY, O.B.E., M.M., A.R.Ae.S.

REVIEWS

•

LONDON
ROYAL AERONAUTICAL SOCIETY, 4 HAMILTON PLACE, W.1

THE LOCKHEED MARK VII
HYDRAULIC PUMP
Outstanding in performance and reputation. For pressures up to 3,000 p.s.i. at 4,000 r.p.m.
Weight only 7 lb. 6 oz.
THE SERVODYNE
The perfect system of power assistance for flying controls. Basic principle minimises 'dead points.'
CANTILEVER STRUTS
used on many famous aircraft.
LOCKHEED HYDRAULIC JACKS
As made for numerous applications ranging from a few hundred lb. thrust to 55,000 lb.
ALL-BRITISH
Lockheed

AUTOMOTIVE PRODUCTS COMPANY LTD., LEAMINGTON SPA

THE ROYAL AERONAUTICAL SOCIETY

GRADUATES' AND STUDENTS' SECTION

August 1950

SOME NOTES ON THE TERMS "*g*" AND "INERTIA"

By M. C. CAMPION, B.Sc.(Eng.), Grad.R.Ae.S.

PARTS I AND II

INTRODUCTION

Students (and other newcomers to aircraft design) frequently find difficulty in appreciating the meaning of a load given in terms of "*g*'s" or of an "inertia load." Since these expressions are in common use they should be fully understood, and it is hoped that the following notes may be of some help.

SUMMARY

The paper deals in turn with:
I—Newton's second law of motion, and the units employed,
II—the use of "inertia" to reduce a dynamic system to an equivalent static state,
III—the application of this method to an aircraft,
IV—some consequences of the flexibility of the structure.
Parts I and II follow, and parts III and IV will be published later.

I—*Newton's second law of motion*

(*i*) This states that a body remains in a state of rest or of uniform motion unless it is compelled to change that state by the application of external forces. It is usually expressed as the equation:

$$P = mf \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where P (poundals) is the force applied to a body of m pounds mass to cause f feet per second^2 acceleration.

This applies to linear motion, the corresponding equation for rotation about the centre of mass being

$$M = I\omega \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where M foot-poundals is the moment applied to a body whose second moment of mass is I pounds-feet^2 to cause an angular acceleration of ω radians per second^2.

(*ii*) The weight of a body is the *force* causing it to accelerate towards the earth:

$$W = mg \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where W poundals is the force causing an acceleration of g feet/second^2 in a body of m pounds mass. The acceleration, g, of a freely falling body, is found to be approximately 32.2 feet/second^2, hence the weight of a body of one pound mass is 32.2 poundals, which is one pound weight.

(*iii*) The pound weight is the practical unit of force, so that equation (1) can be rewritten as:

$$P = 32.2 \times m \times f \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where P is the force in pounds weight, m is the mass in pounds, and f is in feet/second^2.

From this equation it can be deduced that a force of one pound weight accelerates a body of one pound mass at 32.2 feet/second^2, this new unit of acceleration being called one "*g*."

[An alternative deduction, used in aerodynamics, is that a force of one pound weight causes one foot/second^2 acceleration in a body of 32.2 pounds mass, the new unit of mass being called one "slug."]

(*iv*) In a similar manner, equation (2) can be written

$$M = 32.2 \times I \times \omega \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where M is in foot-pounds (the practical unit), I is in pounds-feet^2 and ω in radians/second^2.

From this, one foot-pound moment can be seen to cause 32.2

radians/second^2 acceleration in a body whose second moment of mass is one pound-foot^2. Since g is 32.2 feet/second^2, the new unit of acceleration is one "g/foot," the significance of this unit being apparent later.

[The aerodynamic form again retains the unit of acceleration and changes the unit of second moment of mass to 32.2 pounds-feet^2, or one "slug-foot^2."]

II—*Equivalent static equilibrium*

(*i*) The force accelerating a body is not reacted by other external forces, and the distribution of load in the members of the body cannot be determined by the methods used for static structures. If some reacting forces can be found, then these methods can be employed.

(*ii*) If a force acts at the centre of mass of a rigid body, then every component of the body has the same acceleration in the direction of the force. Since the force need not be applied to each component, it follows that the accelerating force is applied from within the body.

(*iii*) When this force acts, the point of application begins to accelerate, tending to leave the remainder of the body in its original position, so that *relative to the moving point*, every other part of the body is accelerating *in the opposite direction*, and *at the same rate*. This tendency is called "inertia," and the force required to produce the inertia acceleration is the "inertia force" on the component.

(*iv*) If a force P pounds weight acts on a body consisting of a number of components of mass m_1, m_2, m_3.... pounds, and causes it to accelerate at n "g's," then

$$P = n(m_1 + m_2 + m_3 + \ldots .) \quad . \quad . \quad . \quad . \quad (6)$$

The inertia acceleration of each component is n "g's" in the opposite direction, and the inertia forces on the components are P_1, P_2, P_3, and so on, where

$$P_1 = n\,m_1, \text{ etc.} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

so that the total inertia force is

$$P_1 + P_2 + \ldots . = n(m_1 + m_2 + \ldots .) = P. \quad . \quad . \quad . \quad (8)$$

Hence the applied load can be reacted entirely by the sum of the inertia forces on the components and the body is in a state of instantaneous equilibrium.

(*v*) The "inertia factor" of each component is the value by which its mass is multiplied to obtain the inertia force, and is equal to the acceleration, n, measured in "g's."

(*vi*) For angular motion, the moment, M foot-pounds, causes the body to rotate about the centre of mass at α "g's/foot," again tending to leave each component in its original position.

For a component at r_1 feet from the centre of mass, the tangential acceleration is αr_1 "g's" and hence the inertia force (if the mass of the component is m_1 pounds) is $\alpha m_1 r_1$ pounds weight. This has a moment of $\alpha m_1 r_1^2$ foot-pounds (weight) about the centre of mass, and the total "inertia moment" is $\alpha(m_1 r_1^2 + m_2 r_2^2 + \ldots .)$ foot-pounds, which is $\alpha \times$ (second moment of mass), or αI.

But the applied moment, M foot-pounds, acting on the body is also $I\alpha$, so that the sum of the moments of the inertia forces on the components is equal (and opposite) to the applied moment, thus putting the body in a state of instantaneous equilibrium.

(*vii*) If the body lies entirely in one plane, then the tangential acceleration at any point (due to angular acceleration about an axis in that plane) is always normal to the plane. Hence, the linear inertia factor of a component, due to that angular acceleration is always normal to the plane and is given by the product of the "angular inertia factor," α (g's/foot) and the distance of the component from the centre of mass.

The use of the units "g's/foot" for an angular acceleration can be seen from the preceding paragraphs.

(*To be continued*)

THE ROYAL AERONAUTICAL SOCIETY
4 HAMILTON PLACE, PICCADILLY, LONDON, W.1. GROSVENOR 3515-9

NOTICES AUGUST 1950

CONTENTS OF THE AUGUST JOURNAL

Design for Maintenance, R. E. Bishop, C.B.E., F.R.Ae.S.
The Berlin Air Lift, Air Commodore J. W. F. Merer, C.B.
The Drag Effects of Roughness at High Sub-Critical Speeds, A. D. Young, M.A., A.F.R.Ae.S.
Siting of Landing Strips for International Aircraft Movements in Great Britain, William Courtenay, O.B.E., M.M., A.R.Ae.S.
Reviews.

The Council are particularly anxious to encourage members of the Society to support their own Journal by contributions to it of articles and papers on any aspect of Aeronautics. For that purpose they have set aside £250 a year in the form of premium awards to the authors (members or non-members) of such papers and as some reimbursement for the work which has been done by the author. These premium awards are not fixed but vary from five to twenty guineas normally. It is hoped therefore that those members who have written papers on their special subjects will consider their own Journal in the first place.

THE AERONAUTICAL QUARTERLY—Parts I and II, Volume II

Part II, Volume II of "The Aeronautical Quarterly" will be available in the latter half of August from the offices of the Society at 7s. 9d. a copy to members of the Society, post paid, or 10s. 3d. to non-members, post paid.

The Contents of Part II are:—

Critical Mach Numbers for Swept-Back Wings	S. Neumark
General Performance Reduction Equations for Reciprocating-Engined Aircraft with Constant-Speed Propellers ...	W. J. Annand
The Axially-Symmetrical Supersonic Flow Near the Centre of an Expansion	N. H. Johannesen and R. E. Meyer
Note on the Dependence of Flap Hinge Moment Derivatives on Hinge Position	W. J. Duncan
On the Chordwise Lift Distribution at the Centre of Swept Wings	D. Küchemann and J. Weber
Amendments to: "A Note on the Bending Moment Induced in the Booms of a Spar at the point of Application of a Concentrated Load" (Volume I Part IV) ...	H. F. Winny

The Contents of Part I Volume II, copies of which are still available, are:—

Two-Dimensional Theory of Stiffened Plates	Chang O'Chou
The Whirling of a Spinning Top	J. Morris
The Possibility of the Determination of Rate of Climb from Acceleration Measurements in Level Flight ...	E. C. Pike
A Note on Subsonic Aerofoil Theory	John W. Miles
Theory of an Oscillating Supersonic Aerofoil	Geoffrey L. Sewell
The Linearised Theory of Conical Fields in Supersonic Flow, with Applications to Plane Aerofoils	S. Goldstein and G. N. Ward

A few copies of Parts I to IV, Volume I are still available and members are reminded that a strictly limited edition only of "The Aeronautical Quarterly" is printed and numbers cannot be reprinted in any circumstances. An annual subscription therefore is advisable.

BRITISH COMMONWEALTH AND EMPIRE LECTURE

The Sixth British Commonwealth and Empire Lecture will be given by Sir George Cribbett, K.B.E., C.M.G., Deputy Secretary, Ministry of Civil Aviation, on "Some International Aspects of Air Transport with Particular Reference to Future Aircraft Operation." The lecture will be held at The Institution of Civil Engineers, Great George Street, S.W.1 on Thursday 28th September 1950 at 6 p.m. Tea will be served at 5.30 p.m. Members of the Society do not need tickets but they must obtain tickets from the Secretary for guests.

SOCIETY OF BRITISH AIRCRAFT CONSTRUCTORS' EDUCATIONAL GRANTS

The following applicants were awarded Educational Grants by the Society of British Aircraft Constructors at a Selection Committee meeting held in the offices of the Royal Aeronautical Society on 6th July 1950:—

A. W. Smith, Council Nurseries, Little Lane, Ilkley, Yorkshire.
(To Blackburn & General Aircraft Limited.)

B. C. J. Luxton, 25 Hutchings Way, Teignmouth, S. Devon.
(To Westland Aircraft Limited.)

P. H. Durrant, 75 Mandale Road, Horton Bank Top, Bradford.
(To A. V. Roe & Co. Ltd.)

A. C. Wordsworth, 82 Lindenthorpe Road, Broadstairs, Kent.
(To Vickers-Armstrongs Limited, Weybridge.)

M. J. Frey, 55 Wakeman's Hill Avenue, London, N.W.9.
(To de Havilland Aircraft Limited.)

F. G. Appleby, 21 Norman Road, Wembley, Middlesex.
(To Vickers-Armstrongs Limited, Weybridge.)

SYMPOSIUM ON HIGH-TEMPERATURE STEELS AND ALLOYS FOR GAS TURBINES AND THE FIFTH HATFIELD MEMORIAL LECTURE

The Iron and Steel Institute are holding a Symposium on High-Temperature Steels and Alloys for Gas Turbines on Wednesday and Thursday 18th and 19th October 1950. Air Commodore Sir Frank Whittle will read the Fifth Hatfield Memorial Lecture in association with the Symposium on Tuesday 17th October. If those members of the Society who are interested will apply to the Institute full information will be sent to them. The address is: 4 Grosvenor Gardens, London, S.W.1. Telephone Sloane 0061.

MEMBERS' NEW APPOINTMENTS

G. A. Ford, *Associate*—Chief Test Pilot, Cierva Autogiro Co. Limited.

H . R. Gillman, O.B.E., *Associate Fellow*—Director-General, Fédération Aéronautique Internationale, Paris.

M. N. Golovine, M.B.E., A.C.G.I., *Associate Fellow*—Director, Aero Sales, Armstrong-Siddeley Motors Limited.

Professor S. Goldstein, F.R.S., *Fellow*—Professor of Applied Mathematics, College of Technology, Haifa.

J. Hadji-Argyris, *Associate Fellow*—Reader in Aircraft Structures, London University, at Imperial College of Science and Technology. The Readership has only recently been established and this is the first appointment.

J. Hanson, *Fellow*—Chief Superintendent, Aeroplane and Armament Experimental Establishment, Boscombe Down.

E. Krauss, *Associate Fellow*—Aerodynamics Department, Vickers-Armstrongs Limited, Weybridge.

Dr. D. M. A. Leggett, *Associate Fellow*—Reader in Applied Mathematics, London University, at Kings College.

E. Pribram, *Associate Fellow*—Technical Staff, Fairey Aviation Co. Limited.
Dr. S. C. Redshaw, *Fellow*—To the Chair of Civil Engineering at Birmingham University.
P. C. Dunn, *Associate Fellow*—Technical Staff, Tiltman Langley Laboratories.

ELLIOTT MEMORIAL PRIZE

The Elliott Memorial Prize has been awarded to 584266 Murray, A. R.-F.II.A.-Sergeant Aircraft Apprentice, who is the Aircraft Apprentice of the September 1947 Entry who obtained the highest marks in the General Studies Examination.

ASSOCIATE FELLOWSHIP EXAMINATIONS RESULTS

The following candidates were successful in Part I of the Associate Fellowship examinations held in May 1950:—

J. A. H. Bailie	L. F. Nicholls	M. J. Taylor
A. D. Balmain	D. Rowe	E. G. Wilkinson
W. R. Burge	G. A. C. Searle	W. A. Zaremba
B. T. Lewis	P. W. Shaw	

ASSOCIATE FELLOWSHIP EXAMINATIONS—DECEMBER 1950

Candidates wishing to enter for the December 1950 Associate Fellowship Examinations are reminded that forms should be in by 31st August 1950. Entry forms can be obtained on application to the Secretary.

REES JEFFREYS STUDENTSHIP

The Rees Jeffreys Studentship for Research into Transport is open to University graduates and to anyone who is, or has been, engaged in the administration of transport, the construction of transport facilities, or the manufacture of transport equipment.

Full particulars of the Studentship and Application Forms for the 1950-51 Session (which must be returned with a detailed scheme of research) may be obtained from The Registrar, The London School of Economics and Political Science, Houghton Street, Aldwych, W.C.2.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

JOURNAL BINDING

The prices of binding of Journals are as follows:—

1949 Volume (including packing and postage), 15s. 6d.
Previous Volumes (including packing and postage), 17s. 0d.

Journals should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the offices of the Society.

Cases only for unbound 1949 Volumes are available, price 6s. 6d. each. Requests for cases, with remittances, should be sent to the Secretary at the offices of the Society.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

David Offord Buxton, Neville Lewis Fakes (from Graduate), Thiruvalam Kumaraswamy Srinivasa Murthy (from Companion), Arthur Denis Wood (from Graduate).

Associates

Richard Bruce Bolt, Arthur Leslie Briskham, Patrick Bernard George Davies, Albert William Gregg, Ronald Joseph Leonard, Ronald Albert Read, Geoffrey Newland Roberts.

Graduates

David Eric Chandler (from Student), Kenneth Sydney Robert Child (from Student), Daniel John Holding (from Student), John Shaw Hollings, Roff Taylor Jones, Thomas Henry Kerr, Frederick Claude Kinchela (from Student), Kenneth David Little, Kenneth John Mackenzie (from Student), Adam Merton, Peter Milns (from Student), Raymond Peter Murdoch, Derrick George Murkett (from Student), Christopher Lawrence Paice (from Student), Frederick Arthur Alfred Palmer (from Student), Mohamed Saeed, Ramon Schoenberg, Frank Arthur Spong, Denis Sword Whitehead.

Students

David Reginald Ashover, Adrian Roger Ian Austin, Walter Bergwerk, Alan John Billington, Hubert Benoit Jacques De'Jardin, Alfred Laws, David William McCulloch, David Needham, Allan John Noon, Douglas William Pedrick, Reginald Harold Platt, Charles Bernard Pollock, Edward John Scanes, Bir Indra Singh, Harold Lloyd Wood.

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks the return of back numbers of the JOURNAL from L. V. Brown, Esq., *Associate*, and M. N. Dudley, Esq., *ex*-Student.

ADDITIONS TO THE LIBRARY

The following have been added to the Library (titles of pamphlets are printed in italics and books marked * or ** may not be taken out on loan):—

American Helicopter Society and Institute of the Aeronautical Sciences	First Convertible Aircraft Congress. Proceedings. Institute of the Aeronautical Sciences. 1949.
Civil Aeronautics Authority	Film Bibliography of Aviation and Related Fields. U.S. Government Printing Office. 1949.
Davy, M. J. B.	Aeronautics: Lighter - than - Air Craft. H.M.S.O. (Science Museum). 1950.
De Juhasz, K. J. and Meyer, W. E.	Bibliography on Sprays. Texas Co., New York. 1949.
Eckert, E. R. G.	Transfer of Heat and Mass. McGraw-Hill Book Co. 1950.
Hoyle, E.	Sketching for Craftsmen. English Universities Press. 1950.

Lin, C. C.	An Introduction to the Dynamics of Compressible Fluids. Air Materiel Command, Wright Field, Dayton. 1947.
Marton, L. (Editor)	Advances in Electronics. Volume II. Academic Press Inc. 1950.
Naqvi, S. K. I.	Air Transport in India. Kitab Mahal.
Nicolson, M. H.	Voyages to the Moon. Macmillan, New York. 1948.
Smith, G. V.	Properties of Metals at Elevated Temperatures. McGraw-Hill Book Co. 1950.
Wilson, E. E.	Slipstream. The Autobiography of an Air Craftsman. McGraw-Hill. 1950.

N.A.C.A. Technical Notes

1680—*Divergence of swept wings. F. W. Diederich and B. Budiansky.*

2045—*Approximate turbulent boundary-layer development in plane compressible flow along thermally insulated surfaces with application to supersonic-tunnel contour correction. M. Tucker.*

2047—*Pressure distribution and damping in steady roll at supersonic Mach numbers of flat swept-back wings with subsonic edges. H. J. Walker and M. B. Ballantyne.*

2048—*Theoretical lift and damping in roll of thin sweptback tapered wings with raked-in and cross-stream wing tips at supersonic speeds. Subsonic leading edges. K. Margolis.*

2049—*Analysis of factors influencing the stability characteristics of symmetrical twin-intake air-induction systems. N. J. Martin and C. A. Holzhauser.*

2050—*Properties of a boron carbide-iron ceramel. W. G. Lidman and H. J. Hamjian.*

2051—*Spin-tunnel investigation to determine the effect on spin recoveries of reducing the opening shock load of spin-recovery parachutes. I. P. Jones and W. J. Klinar.*

2057—*A method of computing subsonic flows around given airfoils. A. Gelbart and D. Resch.*

2058—*On the continuation of a potential gas flow across the sonic line. L. Bers.*

2066—*Correlation of effects of fuel-air ratio, compression ratio, and inlet-air temperature on knock limits of aviation fuels. L. K. Tower and H. W. Alquist.*

2070—*Knock-limited performance of fuel blends containing ethers. I. L. Drell and J. R. Branstetter.*

2073—*Stress and strain concentration at a circular hole in an infinite plate. E. Z. Stowell.*

2079—*Experiments in external noise reduction of light airplanes. L. L. Beransk, F. S. Elwell, J. P. Roberts and C. F. Taylor.*

2080—*Wind-tunnel investigation at low speed of an unswept untapered semispan wing of aspect ratio 3.13 equipped with various 25-per cent.-chord plain flaps. J. S. Johnson and J. R. Hagerman.*

2082—*A review of information on the mechanical properties of aluminum alloys at low temperatures. K. O. Bogardus, G. W. Stickley and F. M. Howell.*

2083—*Theoretical analysis of various thrust-augmentation cycles for turbojet engines. B. T. Lundin.*

2086—*Hovering and low-speed performance and control characteristics of an aerodynamic-servocontrolled helicopter rotor system as determined on the Langley helicopter tower. P. J. Carpenter and R. S. Paulnock.*

2087—*Comparison of theoretical and experimental heat transfer on a cooled 20 degree cone with a laminar boundary layer at a Mach number of 2.02. R. Scherrer and F. E. Gowen.*

2088—*Performance and load-range characteristics of turbojet engine in transonic speed range. B. Lubarsky.*

2089—*A comparison of the lateral controllability with flap and plug ailerons on a swept-back wing model. P. M. Lovell and P. P. Stassi.*

2095—*Application of the wire-mesh plotting device to incompressible cascade flows. W. R. Westphal and J. C. Dunavant.*

2097—*Improvement of high-temperature properties of magnesium-cerium forging alloys. K. Grube, J. A. Davis, L. W. Eastwood, C. H. Lorig and H. C. Cross.*

2098—*The effects of stability of spin-recovery tail parachutes on the behaviour of airplanes in gliding flight and spins. S. H. Scher and J. W. Draper.*

N.A.C.A. Technical Memoranda

1222—*Investigation of the model ME.210 in the spin wind tunnel of the DVL. Fourth Partial Report—Model with long fuselage and with a vee-tail. A. Huffschmid.*

1252—*Some studies on the flow of a gas in the region of transition through the velocity of sound. I. A. Kiebel.*

1255—*Equations of motion of a rocket. F. R. Gantmacher and L. M. Levin.*

1257—*Vibration of a wing of finite span in a supersonic flow. M. D. Haskind and S. V. Falkovich.*

1266—*Preliminary results from fatigue tests with reference to operational statistics. E. Gassner.*

1270—*The gas kinetics of very high flight speed. E. Sanger.*

1275—*The solution of the laminar-boundary-layer equation for the flat plate for velocity and temperature fields for variable physical properties and for the diffusion field at high concentration. H. Schuh.*

N.A.C.A. Reports

885—*Flight investigation on a fighter-type airplane of factors which affect the loads and load distribution on the vertical tail surfaces during rudder kicks and fishtails. J. Boshar.*

930—*An analytical method of estimating turbine performance. F. D. Kochendorfer and J. C. Nettles.*

A.R.C. Reports and Memoranda

2275—*The response of an aeroplane to application of the elevators. L. W. Bryant and R. W. G. Gandy.*

2303—*Collected researches on the stability of kites and towed gliders. L. W. Bryant, W. S. Brown and N. E. Sweeting.*

A.R.C. Technical Reports

1—*Some notes on the flapping motion of rotor blades. J. B. B. Owen.*

2—*Tests in the N.P.L. electric tank on a 4.1 axi-symmetrical diffuser having a discontinuity in the wall velocity. F. Cheers and W. G. Rayner.*

3—*Water stability tests on Saro 37 fitted with Shetland hull bottom wing tip floats and tail. I. W. McCaig.*

5—*Note on the interference on a part-wing mounted symmetrically on one wall of a wind tunnel of octagonal section. H. C. Garner.*

7—*Report on measurements of the pressure distribution over a wing of triangular plan form at a Mach number of 2.44. G. H. Lean and K. G. Whitaker.*

8—*The application of jet propulsion to helicopters. W. Stewart and M. F. Burle.*

9—*Note on sintered metal with a view to its use as a porous surface in distributed suction experiments. H. H. Preston and A. G. Rawcliffe.*

12—*Transitional friction effects in powered controls with particular reference to hydraulic jacks. F. Holoubek.*

College of Aeronautics

35—*A comparison of the calculated profile drag coefficients of various low drag wing sections. E. M. Dowlen.*

37—*Wave reflection near a wall. A. Robinson.*

Australia—Aeronautical Research Laboratories

SM.148—*A static strain indicator with amplifier. F. W. Hooton.*

Civil Aeronautics Administration

104—*The slope line approach light systems. H. J. Cory Pearson.*

105—*Developments of aircraft windshields to resist impact with birds in flight, Part III. Impact characteristics of aircraft windshields incorporating Polyvinyl Butyral plastic interlayer. P. Kangas and G. L. Pigman.*

O.N.E.R.A.

40—*Eléments d'acoustique aéronautique. P. Lienard, M. Kobrynski and P. Antzenberger.*

41—*Tables des coefficients aérodynamiques instationnaires régime plan supersonique, Part I. Exposé sommaire de la méthode de L. Schwartz et introduction aux tables. R. Weber. Part II, Tables numériques des coefficients aérodynamiques instationnaires. R. Weber.*

42—*Les calculs matriciel et spinoriel. J. M. Souriau.*

Publications Scientifiques et Techniques du Ministere de l'Air

239—*Etude de matériaux a grand amortissement. Liège et caoutchouc. A. Brodeau.*

J. LAURENCE PRITCHARD,
Secretary.

Lewes Press (Wightman & Co. Ltd.), Friars Walk, Lewes, Sussex.

B.O.A.C. TAKES GOOD CARE OF YOU

TO South America

Consult your local B.O.A.C. Appointed Agent about fast Argonaut services to the east coast of South America and over the Andes to Santiago. He'll tell you about the pressurized comfort of these famous four-engined airliners with two roomy cabins and rear lounge.

He'll also tell you about other B.O.A.C. services to fifty-one countries on all six continents. He makes no charge for advice, information or bookings.

GET THERE SOONER! STAY THERE LONGER!

FLY BRITISH BY **B·O·A·C**

BRITISH OVERSEAS AIRWAYS CORPORATION

Airways Terminal, Buckingham Palace Road, London, S.W.1. Telephone: VICtoria 2323

SILICONES

are already important to the

AIRCRAFT INDUSTRY

Silicones have heat-resisting and water-repellent properties that have important applications in the Aircraft Industry. They can be used in the form of Liquids, Resins, Greases and Rubbers (Silastic).

SILICONE FLUIDS are subject to low viscosity changes over wide temperature ranges. They are suitable for damping, hydraulic and instrument fluids.

SILICONE RESINS AND VARNISHES are heat-stable and water-repellent. They provide electrical insulation that is serviceable at temperatures at least 50°C. above Class B limits.

SILICONE GREASES AND COMPOUNDS are lubricants suitable for bearings and valves operating at high and low temperatures. DC4, the Ignition Sealing Compound, has many applications.

SILASTIC is a rubber-like material that remains flexible over the temperature range of —50° to 260°C. It is suitable for special purpose gaskets, and for insulating electrical wires and cables.

Albright & Wilson are developing the use of silicones in this country. They will be glad to send fuller particulars of these products.

SILICONES

ALBRIGHT & WILSON LTD

Distributors of Dow Corning Silicones

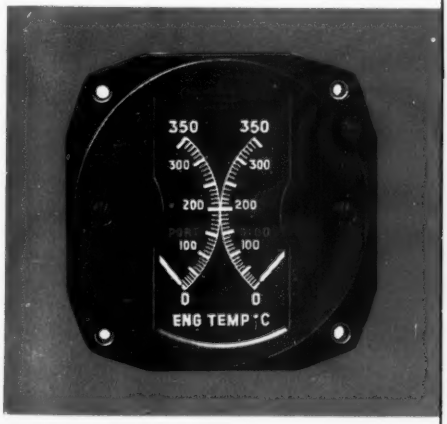
49 PARK LANE · LONDON · W.1 · TEL: GRO. 1311

TAW 109

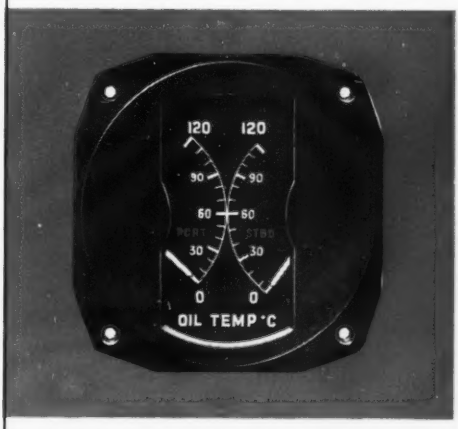
WESTON
AIRCRAFT INSTRUMENTS

No. 1. Temperature Measuring

The comprehensive range of Weston temperature measuring instruments covers the requirements of existing production aircraft, as well as types now under development. In addition to thermometry for the indication of cylinder, air, oil and radiator temperatures, Weston equipment for aircraft includes instruments for supply, navigational aid instruments, selector switches, etc.



Model S. 128. Dual Engine Temperature Indicator, comprising two Millivoltmeters of 100° scale housed in large-size S.A.E. case. For use in conjunction with copper/constantan, iron/constantan, or chrome/alumel thermocouples.



Model S. 127. Dual Ratiometer Indicator, comprising two 100° ratiometer movements housed in large-size S.A.E. case. For use in conjunction with thermometer bulbs, electrical oil pressure transmitters, electrical position indicators or any combination of two of these to indicate a variety of temperatures, pressures or positions

SANGAMO WESTON LIMITED · Enfield · Middlesex

Tel.: Enfield 3434 (6 lines) and 1242 (4 lines). Grams: Sanwest, Enfield

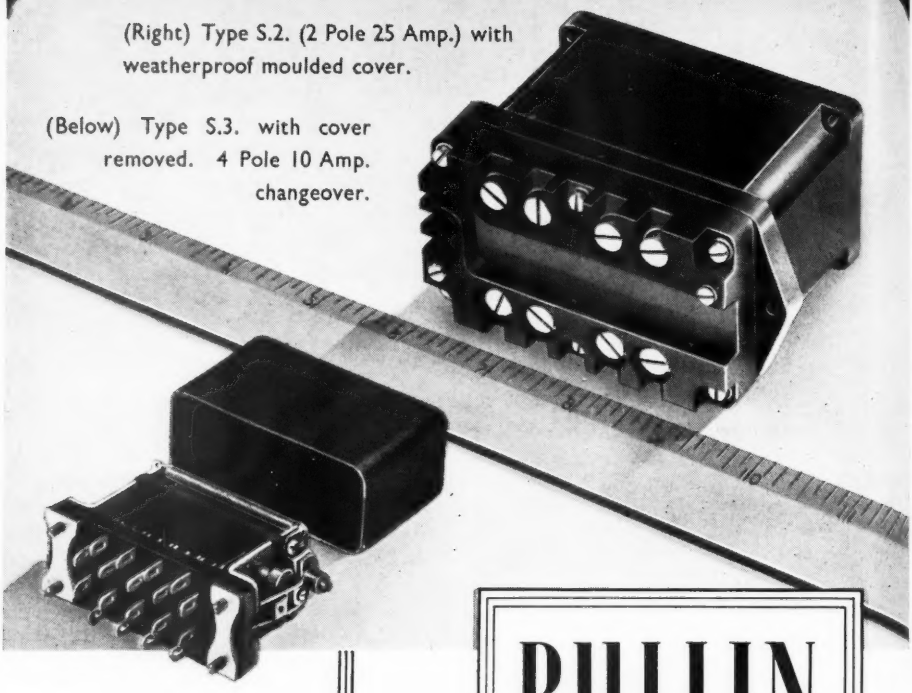
Scottish Factory: Port Glasgow · Renfrewshire · Scotland

Area Depots: 201 St. Vincent St., Glasgow, Tel.: Central 6208. Milburn House, Newcastle-on-Tyne, Tel.: Newcastle 26867. 22 Booth St., Manchester, Tel.: Central 7904. 33 Princess St., Wolverhampton, Tel.: Wolverhampton 21917

Precision MULTI-POLE RELAYS

(Right) Type S.2. (2 Pole 25 Amp.) with weatherproof moulded cover.

(Below) Type S.3. with cover removed. 4 Pole 10 Amp. changeover.



PULLIN

Pullin relays are used by the majority of Aircraft Manufacturers in addition to

THE MINISTRY OF SUPPLY

THE ADMIRALTY AND

THE WAR OFFICE

LOW-VOLTAGE HEAVY-DUTY RELAYS

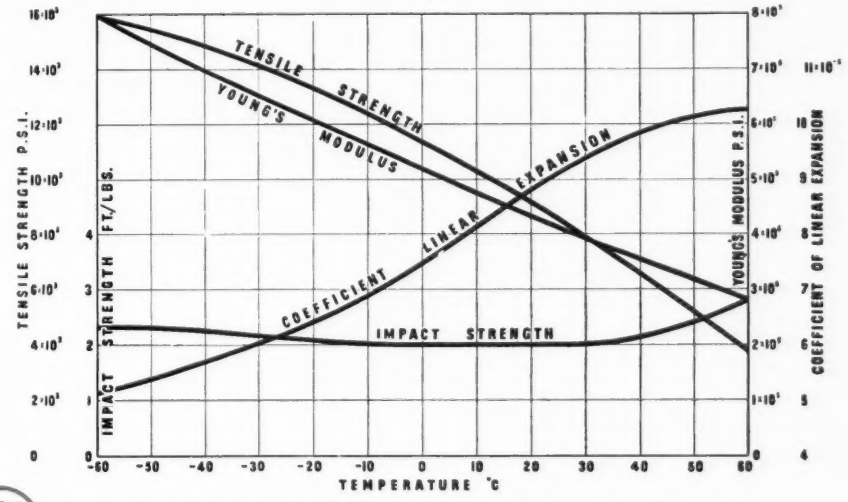
Fully approved for 12 or 24 V D C. Compact, robust, light in weight. Consumption is less that 5 Watts. These change-over relays are adaptable for operation under many varied conditions. Write for further details.

R. B. PULLIN & CO. LTD., PHŒNIX WORKS, GREAT WEST ROAD, BRENTFORD, MIDDLESEX. *Tel.* EAL 0011/3 3661/3

15747A

Physical properties of 'PERSPEX' acrylic sheet

—variation with temperature



"PERSPEX' is the registered trade mark of the acrylic sheet manufactured by I.C.I.

For Literature and further information apply to

PLASTICS DIVISION · IMPERIAL CHEMICAL INDUSTRIES LTD

Welwyn Garden City · Herts.

P 415

Mark 26 Double chair with adjustable footrest

AT81

They *all* approve
VICKERS-ARMSTRONGS AIRCRAFT CHAIRS

The designer is mainly concerned with the weight and shape of a chair. The operator requires a chair that will meet the special requirements of the routes on his schedule. The passenger must have complete comfort whether he wishes to relax, read or sit up and admire the view. Because Vickers aircraft chairs satisfy *everyone*, B.O.A.C. have chosen them for the Solent Flying Boats and Hermes, Comet and Argonaut aircraft.

Mark 25 Single chair

Mark 27 Triple chair

VICKERS-ARMSTRONGS LIMITED · AIRCRAFT DIVISION · WEYBRIDGE · SURREY

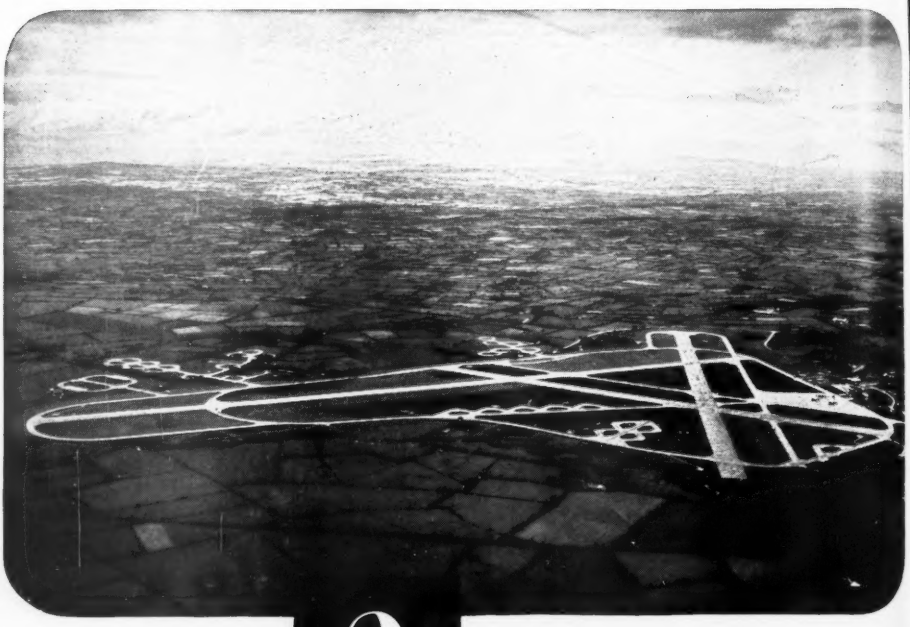
is a hot favourite . . .

No wonder there are so many takers for an alloy which combines excellent hot working properties with high specific strength—or that ' Hiduminium ' RR 56 is now established as one of the most popular high-strength alloys in a large field. Produced with high uniform quality and free from ingot defects, RR 56 is suitable for a wide range of components up to a size limited only by plant capacity. But, no matter how large the component, RR 56, like all the other alloys in the ' Hiduminium ' range, is light in relation to its strength. Many manufacturers

. . make light work of it with **Hiduminium** AND MAGNUMINIUM

HIGH DUTY ALLOYS LTD., SLOUGH, BUCKS. Telephone: Slough 21201. INGOT, BILLETS, FORGINGS, CASTINGS & EXTRUSIONS IN 'HIDUMINIUM' & 'MAGNUMINIUM' (Registered Trade Marks) ALUMINIUM & MAGNESIUM ALLOYS.

Do you know your airfields?



2

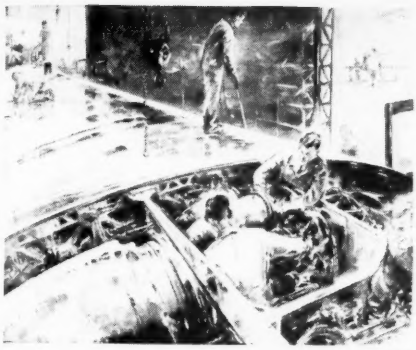
Recognise this airfield? It's No. 2 of a new series of puzzle photographs. You'll find the answer upside down below. ★

The Shell BP Aviation Service supplies fuel and lubricants to twenty-three international air lines and countless charter companies, flying clubs and private fliers. The service is on duty all the year round at twenty-five aerodromes throughout the country.

Shell BP Aviation Service

Shell-Mex and BP Ltd., Shell-Mex House, Strand, W.C.2.
Distributors in the U.K. for the Shell
and Anglo-Iranian Oil Groups.

★ Nutts Corner, Belfast



A3A

The increasing speed and weight of modern aircraft demands the best possible materials. More and more designers specify

DURALUMIN

REGD. TRADE MARK

The strong light aluminium alloy marketed solely by BOOTH BIRMINGHAM

JAMES BOOTH AND COMPANY LIMITED

ARGYLE STREET WORKS · BIRMINGHAM · 7

DATA SHEETS

ON

AERODYNAMICS

STRESSED SKIN STRUCTURES

PERFORMANCE

And Now

FUELS & LUBRICANTS

(prepared in conjunction with the Institute of Petroleum)

Write for full particulars to:

The Royal Aeronautical Society

4 HAMILTON PLACE, LONDON, W.1.

B T-H

Electric Equipment for Aircraft

With unrivalled manufacturing resources, backed by continual research and development and fifty-three years' experience, BTH enjoys an enviable reputation for the quality of its products. Reliability is of prime importance on land, but is vital in the air, hence the success of BTH aircraft magnetos, and electrical equipment including:

Motor-generating sets with electronic regulators · Gas-operated turbo-starters · Actuators · A.C. and D.C. Motors · Generators · Mazda lamps, etc.

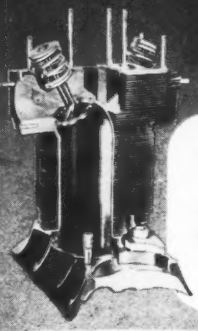
BRITISH THOMSON-HOUSTON

THE BRITISH THOMSON-HOUSTON CO., LTD., COVENTRY, ENGLAND

A4039

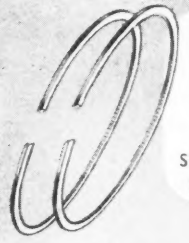
WELLWORTHY

Quality Products



AL-FIN
INTEGRAL BI-METALLIC BONDING OF IRON AND ALUMINIUM

PISTONS
OF EVERY TYPE FOR EVERY APPLICATION



PISTON RINGS
FOR AERO ENGINES AND SEALING RINGS FOR GAS TURBINES

We shall be glad to hear if you are interested in any problem concerning Pistons or Piston Rings. AL-FIN Bonding, the newest development combining weight saving with maximum heat transfer is exclusive to Wellworthy in this country. Full details will be sent on request.

WELLWORTHY PISTON RINGS LTD
RADIAL WORKS LYMINGTON HANTS

THE AERONAUTICAL QUARTERLY

Volume II MAY 1950 Part I

CONTENTS

Two-Dimensional Theory of Stiffened Plates	*Chang O'Chou*
The Whirling of a Spinning Top	*J. Morris*
The Possibility of the Determination of Rate of Climb from Acceleration Measurements in Level Flight	*E. C. Pike*
A Note on Subsonic Aerofoil Theory	*J. W. Miles*
Theory of an Oscillating Supersonic Aerofoil	*Geoffrey L. Sewell*
The Linearised Theory of Conical Fields in Supersonic Flow, with Applications to Plane Aerofoils	*S. Goldstein and G. N. Ward*

LONDON
ROYAL AERONAUTICAL SOCIETY
4 HAMILTON PLACE W1

10/-

THE AERONAUTICAL QUARTERLY

Volume II AUGUST 1950 Part II

CONTENTS

Critical Mach Numbers for Swept-Back Wings	*S. Neumark*
General Performance Reduction Equations for Reciprocating-Engined Aircraft with Constant - Speed Propellers	*W. J. D. Annand*
The Axially - Symmetrical Supersonic Flow Near the Centre of an Expansion	*N. H. Johannesen and R. E. Meyer*
Note on the Dependence of Flap Hinge Moment Derivatives on Hinge Position	*W. J. Duncan*
On the Chordwise Lift Distribution at the Centre of Swept Wings	*D. Kucheman and J. Weber*

LONDON
ROYAL AERONAUTICAL SOCIETY
4 HAMILTON PLACE W1

10/-

One of the de Havilland Propeller-Test Tunnels at Hatfield.

ESSENTIAL SOURCES OF INFORMATION

'The Aeroplane' provides the men engaged in aviation with accurate and up-to-date information not only in their particular specialised fields, but also on progress in allied branches of aeronautical development. Factual and fully illustrated articles deal with research, development, construction and operation, and—taking note of the needs of busy men—'The Aeroplane' succeeds in surveying the wide field of the industry in concise and readable form.

Fridays, One Shilling
£3 . 1 . 0 a year,
post free.

TEMPLE PRESS LIMITED

BOWLING GREEN LANE, LONDON, E.C.1. TERMINUS 8644

THE MOTOR · THE COMMERCIAL MOTOR · CYCLING · PLASTICS · THE MOTOR SHIP · THE AEROPLANE
THE OVERSEAS ENGINEER · THE LIGHT CAR · THE MOTOR BOAT AND YACHTING · LIGHT METALS
BRITISH FARM MECHANIZATION · MOTOR CYCLING · THE OIL ENGINE AND GAS TURBINE

LINKING AUSTRALIA
PACIFIC ISLANDS
AND THE EAST
WITH THE U.K.

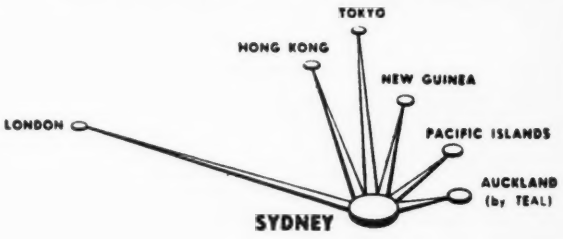
Q·E·A

AUSTRALIA'S INTERNATIONAL AIRLINE

Services: LONDON—SYDNEY via Italy, Egypt, Pakistan, India, Ceylon, Singapore and Java by Kangaroo Service, in parallel with B.O.A.C. SYDNEY—HONG KONG via Labuan. SYDNEY—TOKYO via Manila. SYDNEY—NEW GUINEA via Northern Queensland airports. SYDNEY—PACIFIC ISLANDS including Lord Howe, Norfolk Island, Noumea and Suva. SYDNEY—AUCKLAND (by T.E.A.L.) links with Kangaroo Service. *Full details from all travel agents.*

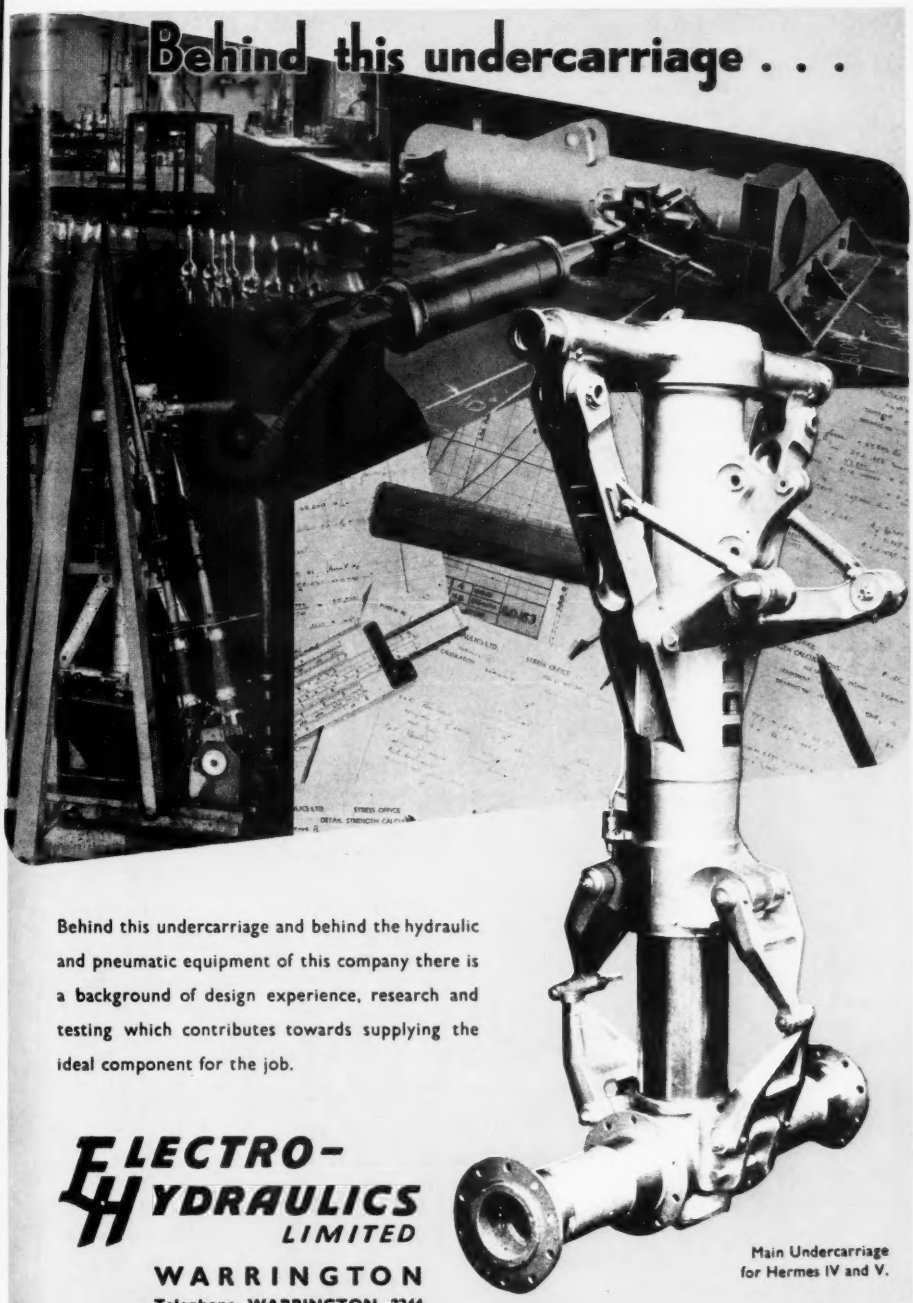
QANTAS EMPIRE AIRWAYS

Australia's International Airline—Operating regular services on over 30,000 miles of unduplicated air routes



IN ASSOCIATION WITH BRITISH OVERSEAS AIRWAYS CORPORATION

Behind this undercarriage . . .



Behind this undercarriage and behind the hydraulic and pneumatic equipment of this company there is a background of design experience, research and testing which contributes towards supplying the ideal component for the job.

ELECTRO-HYDRAULICS LIMITED

WARRINGTON

Telephone WARRINGTON 2244

Main Undercarriage for Hermes IV and V.

DESIGNERS & MANUFACTURERS OF HYDRAULIC, PNEUMATIC AND ELECTRIC EQUIPMENT

I.N.931

40 years progress . . .

On February 19th, 1910, The Bristol Aeroplane Company Limited was founded. The "Box-Kite"—first production aircraft—began a record of nearly 200 "Bristol" types. Fighter, Bulldog, Blenheim, Beaufort, Beaufighter and Brigand are a few aircraft names which, with Jupiter, Pegasus, Hercules and Centaurus engines, have made "Bristol" a name world-renowned in aviation. The Bristol Aeroplane Company Limited points with pride to a forty-year record of steady progress achieved largely by the encouragement of individual thought and enterprise among its workers.

THE Bristol AEROPLANE COMPANY LIMITED · ENGLAND

THE SOCIETY'S AWARDS

The Society offers a number of valuable awards, most of them annually. Full particulars of the conditions attaching to these awards may be obtained on application to the Secretary.

Society's Gold Medal

The highest honour which the Society can confer for work of an outstanding nature in aeronautics.

Society's Silver Medal

Awarded for work of an outstanding nature in aeronautics.

Society's Bronze Medal

Awarded for work leading to advance in aeronautics.

British Gold Medal for Practical Achievement in Aeronautics

Awarded for outstanding practical achievement leading to advancement in aeronautics.

British Silver Medal for Practical Achievement in Aeronautics

Awarded for practical achievement leading to advancement in aeronautics.

Wakefield Gold Medal

Awarded annually, at the discretion of the Council, to the designer or inventor of any apparatus tending towards safety in flying.

The George Taylor (of Australia) Gold Medal

Awarded annually, at the discretion of the Council, for the most valuable paper read during the previous session.

Simms Gold Medal

Awarded annually, at the discretion of the Council, for the most valuable contribution read before, or received by, the Society on any subject allied to aeronautics, *e.g.* structures, meteorology, metrology, etc.

Herbert Akroyd Stuart Memorial Prize

Awarded at the discretion of the Council for the most valuable contribution read before, or received by, the Society on applied thermodynamics.

Edward Busk Memorial Prize

Awarded annually, at the discretion of the Council, for the most valuable contribution read before, or received by, the Society on applied aerodynamics.

Orville Wright Prize

Offered annually for the best contribution on some subject of a technical nature in connection with aeronautics, which is received by the Society and published in *The Aeronautical Quarterly*.

Pilcher Memorial Prize

Awarded annually, at the discretion of the Council, for the most valuable paper read by a Graduate or Student during the previous year at any meeting of the Society or its Branches.

Usborne Prize

Awarded annually, at the discretion of the Council, for the best contribution to the Society's publications written by a Graduate or Student on some subject of a technical nature in connection with aeronautics.

R. P. Alston Memorial Prize

Awarded for practical achievement associated with the flight testing of aircraft.

Major Baden-Powell Memorial Prize

Awarded to the best entrant in the Associate Fellowship Examination.

Wilbur Wright Memorial Premium

The Wilbur Wright Memorial Lecture is held annually, a premium of £75 being awarded to the lecturer, if British, or £125 if he is an American, invited by the Council to deliver the lecture. The lecture is usually given alternately by an American and an Englishman, and is the most important aeronautical lecture of the year.

British Commonwealth and Empire Lecture

The British Commonwealth and Empire Lecture is delivered annually by a lecturer chosen in alternate years from the British Dominions and Colonies and Great Britain.

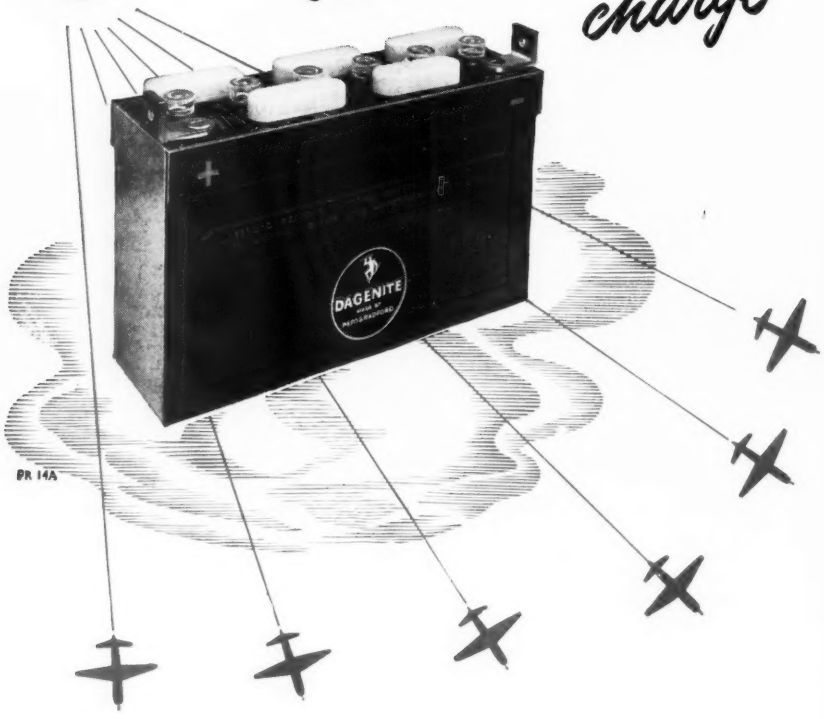
The British Commonwealth and Empire Lecture has a premium of £50 and in the case of lecturers from the Dominions and Colonies an allowance is paid towards the lecturer's expenses.

Branch Prize

The Council offer an annual prize of twenty guineas for the best paper read before the Branches during the previous lecture session. The prize is open to any member of the Society or of any Branch.

ON THE DE HAVILLAND COMET...

6 Successive starts on one battery charge



Although ground starting of the jet engines is the normal procedure, these batteries have been specially designed to start the Comet from inside the aircraft when required. On test recently a fully-charged 24-volt set of batteries gave six successive starts without any charge during the intervening 5-minute rest periods. An exceptional performance for a 60 ampere-hour battery weighing only 52¾ lb.

DAGENITE AIRCRAFT BATTERIES

PETO AND RADFORD 50 GROSVENOR GARDENS · LONDON · SW1

OFFICIALS OF THE BRANCHES OF THE SOCIETY IN THE UNITED KINGDOM

BELFAST
President: Professor G. T. R. HILL, M.C., M.Sc., M.I.Mech.E., F.R.Ae.S.
Chairman: Rear Admiral M. S. SLATTERY, C.B., F.R.Ae.S., R.N. (Retd.).
Secretary: J. A. KIRK, Esq., A.F.R.Ae.S., Short Brothers & Harland Ltd., Queen's Island, Belfast, N.I.

BIRMINGHAM
President: S. C. REDSHAW, Esq., F.R.Ae.S.
Secretary: C. P. HOMES, Esq., A.R.Ae.S., 81 Peplins Way, Kings Norton, Birmingham, 30.

BRISTOL
President: Air Chief Marshal Sir ARTHUR BARRATT, C.M.G., M.C.
Chairman: F. H. POLLICUTT, Esq., F.R.Ae.S.
Hon. Secretary: J. M. HAHN, Esq., Structures Dept., Aircraft Division, Bristol Aeroplane Co. Ltd., Filton, Bristol.

BROUGH
President: R. BLACKBURN, Esq., O.B.E., A.M.I.C.E., M.I.Mech.E., F.R.Ae.S.
Chairman: G. E. PETTY, Esq., M.I.Mech.E., F.R.Ae.S.
Secretary: F. A. WILKINSON, Esq., A.F.R.Ae.S., Design Office, Blackburn & General Aircraft Ltd., Brough, E. Yorks.

COVENTRY
President: H. M. WOODHAMS, Esq., C.B.E., [F.R.Ae.S.
Chairman: W. J. PETERS, Esq. [Ltd.
Secretary: C. T. SCULTHORPE, Esq., A.F.R.Ae.S., Design Dept., Sir W. G. Armstrong Whitworth Aircraft Baginton, Coventry.

DERBY
President: E. W. HIVES, Esq., C.H., M.B.E., F.R.Ae.S.
Chairman: A. G. ELLIOTT, Esq., C.B.E., F.R.Ae.S.
Secretary: J. L. BATCHELOR, Esq., A.R.Ae.S., 154 Littleover Lane, Derby.

GLASGOW
Chairman: T. B. LYON, Esq., A.F.R.Ae.S.
Secretary: G. YOUNG, Esq., B.Sc., M.I.Ae.S., [A.F.R.Ae.S., c/o Design Office, Scottish Aviation Ltd., Prestwick Airport, Ayrshire.

GLOUCESTER AND CHELTENHAM
President: A. L. MILNER, Esq., Wh.Sc., A.M.I.C.E., F.R.Ae.S.
Chairman: R. W. WALKER, Esq., F.R.Ae.S.
Secretary: C. E. HUTT, Esq., c/o S. Smith & Sons Ltd., Bishops Cleeve, Cheltenham.

HALTON
Station Headquarters, Royal Air Force, Halton, Aylesbury, Bucks.

HATFIELD
President: Sir GEOFFREY DE HAVILLAND, C.B.E., A.F.C., R.D.I., Hon.F.I.Ae.S., F.R.Ae.S.
Chairman: J. E. WALKER, Esq., A.F.R.Ae.S.
Secretary: E. J. MANN, Esq., A.M.I.Mech.E., de Havilland Aircraft Co. Ltd., [A.R.Ae.S. Hatfield, Herts.

ISLE OF WIGHT
President: Sir ARTHUR GOUGE, B.Sc., M.I.Mech.E., F.R.Ae.S.
Chairman: H. KNOWLER, Esq., A.M.I.C.E., F.R.Ae.S.
Secretary: P. H. CURNOW, Esq., Grad.R.Ae.S., Design Office, Saunders-Roe Ltd., Osborne, I.o.W.

LEICESTER
Chairman: W/Cdr. H. E. FALKNER, A.F.R.Ae.S.
Secretary: F. WATKIN, Esq., B.Sc., A.F.R.Ae.S., Auster Aircraft Ltd., Rearsby, Leicester.

LUTON
Chairman: S. A. CLARKE, Esq., A.F.R.Ae.S.
Secretary: P. A. DRILLIEN, Esq., A.R.Ae.S., c/o D. Napier & Son Ltd., Luton, Beds.

MANCHESTER
President: Sir ROY H. DOBSON, C.B.E., J.P., F.R.Ae.S.
Chairman: C. E. FIELDING, Esq., O.B.E., M.I.P.E., A.F.R.Ae.S.
Secretary: J. A. E. WATERFALL, Esq., 56 Manor Avenue, Ashton-on-Mersey, Cheshire.

PORTSMOUTH
President: A. TOWNSLEY, Esq.
Chairman: E. C. GREEN, Esq.
Secretary: E. M. BELLAMY, Esq., c/o Airspeed Ltd., The Airport, Portsmouth, Hants.

PRESTON
President: Sir GEORGE NELSON, M.I.Mech.E., M.I.E.E.
Secretary: D. B. SMITH, Esq., O.B.E., M.A., A.M.I.Mech.E., A.F.R.Ae.S., English Electric Co. Ltd., Aircraft Division, Warton Aerodrome, Nr. Preston, Lancs.

READING
President: Sir FREDERICK HANDLEY PAGE, C.B.E., Hon.F.R.Ae.S.
Chairman: E. W. GRAY, Esq., B.Sc., A.M.I.Mech.E., A.F.R.Ae.S.
Secretary: E. L. PEARSON, Esq., A.R.Ae.S., c/o Handley Page (Reading) Ltd., The Aerodrome, Woodley, Reading, Berks.

SOUTHAMPTON
Chairman: A. N. CLIFTON, Esq., F.R.Ae.S.
Secretary: T. TANNER, Esq., A.F.R.Ae.S., University College, Southampton, Hants.

WEYBRIDGE
President: G. R. EDWARDS, Esq., M.B.E., B.Sc., F.R.Ae.S.
Chairman: H. H. GARDNER, Esq., B.Sc., F.R.Ae.S.
Secretary: J. H. SINCLAIR, Esq., A.R.Ae.S., Vickers-Armstrongs Ltd., Weybridge, Surrey.

YEOVIL
Secretary: L. A. LANSDOWN, Esq., A.F.R.Ae.S., Westland Aircraft Ltd., Yeovil, Somerset.

Airwork Viking over the Nile North of Khartoum

AIRWORK
LIMITED
Charter Division

The Contract Charter Division is yet another important section of the world-wide organisation of Airwork Limited. With its home base at Blackbushe Airport, Surrey, Airwork employs 48 aircraft; 66 seasoned pilots; 30 other crew as well as a team of efficient air hostesses. Backed by the organisation's own Repair and Maintenance sections — an advantage few firms can claim — it is able to provide all-in, self-contained service unrivalled for smoothness and dependability of operation. Outcome of eighteen years' planned development, Airwork Charter Division forges yet another link in a progressively developed chain of closely inter-related services designed to appeal especially to all interested in long-term charter work.

THE SERVICES OF AIRWORK

● Air Transport Contracting ● Contract Charter Flying ● Servicing and Maintenance of Aircraft ● Overhaul and Modification of Aircraft ● Sale and Purchase of Aircraft ● Operation and Management of Flying Schools and Clubs ● Specialised Aerodrome Catering ● Insurance

AIRWORK LIMITED • 15 CHESTERFIELD STREET • LONDON • W.1 • TEL.: GROSVENOR 4841

Also at: Gatwick Airport, Horley, Surrey. Blackbushe Airport, Nr. Camberley, Surrey. Langley Aerodrome, Bucks. Heston Airport, Middlesex. Loughborough Aerodrome, Dishley, Leics. Perth Aerodrome, Perthshire. Renfrew Airport, Renfrewshire.

THE ROYAL AERONAUTICAL SOCIETY

PAPERS FOR THE JOURNAL

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the JOURNAL. Both members and non-members are invited to contribute original papers on their own special subjects. The following notes on the preparation of papers for the JOURNAL are given to assist contributors:—

COPYRIGHT

The copyright of every paper printed in the JOURNAL shall be the property of Aerial Science Limited. If the author makes use of copyright material in his paper or information obtained by reason of his employment or otherwise, he must state clearly in his covering letter, or in the paper, that consent has been given for the use of such material.

MANUSCRIPTS

Papers must be in English, in the third person, and typed on one side of the paper only, with double spacing and wide margins. When submitted they must be in their *final form for publication*. Only typographical errors may be corrected in proofs. Titles of papers should be brief.

Where practicable, a summary of not more than 250 words should be given at the beginning of the paper, giving its scope and conclusions.

All references should be numbered in the text where they occur, and the complete list of references given at the end of the manuscript. These references will be published at the end of the text. Footnotes should be numbered consecutively. Tables should be kept as concise as possible.

ILLUSTRATIONS

Illustrations must be drawn so that they will reduce to column or two-column width, that is to $2\frac{5}{8}$ or $5\frac{1}{2}$ inches. Full page illustrations must reduce to $5\frac{1}{2}$ inches by 8 inches. All drawings must be in black ink on white paper or tracing cloth.

Lettering and figures on drawings must be in pencil only. Drawings should be posted flat or rolled.

Photographs should not be less than half plate in size and must be clear black and white glossy prints.

Every drawing and photograph should have on the back its figure number and title.

MATHEMATICS

Only very simple symbols and formulæ should be typewritten. All others should be written carefully by hand in ink. Ample space for marking should be allowed above and below all equations. Greek letters should be designated by name in the margin.

The difference between capital and lower-case letters should be clearly shown; care should be taken to avoid confusion between zero (0) and the letter o, between the numeral one (1) and the letter l, between alpha and a, kappa and k, mu and u, nu and v, eta and n.

All subscripts and exponents should be clearly marked, and dots, bars, and so on, over letters should be avoided as far as possible.

Square roots of complicated expressions should be written with the exponent $\frac{1}{2}$ rather than with the sign $\surd$.

Complicated exponents and subscripts should be avoided. Any complicated expression that recurs frequently should be represented by a special symbol.

Unless an abbreviation is one recognised as standard practice, both in this and other English-speaking countries, for example, b.h.p. for brake horse power, the meaning should be given in full on its first use.

D. NAPIER & SON LIMITED · LONDON W.3

DESIGN FOR MAINTENANCE

by

R. E. BISHOP, C.B.E., F.R.Ae.S.

The 794th Lecture to be read before the Royal Aeronautical Society was given on 2nd March 1950 at the Institution of Civil Engineers, Great George Street, London, S.W.1. Sir John S. Buchanan, C.B.E., F.R.Ae.S., President of the Society, introduced the Lecturer, Mr. R. E. Bishop, C.B.E., F.R.Ae.S., Chief Designer, and a Director of The de Havilland Aircraft Co. Ltd.

THERE is nothing new in attempting to design an aircraft to give trouble-free service. This has always been one of the major parts of a designer's job. In recent years there has been a lot of talk about improving design from the maintenance point of view and suggestions for "maintenance cells" in drawing offices. I would suggest that if aircraft have become too difficult to maintain, it is not entirely due to lack of appreciation of the problem in the drawing office, but mainly to the great increase in complexity of the modern aircraft, particularly in the past 10 years. A great deal of this complication is due to equipment and automatic gadgetry. The remedy rests to a large extent with the people who specify this equipment and to some extent with the designer, who seems to have been far too willing to accept any "requirement" without first having satisfied himself that it is in the best interests of the aeroplane as a whole.

When it is realised that between 25 and 40 per cent. of the total direct operating costs of an airline are due to maintenance, quite apart from the losses due to machines not being serviceable when required, it at once becomes apparent that there is a very worth-while gain to be had from a real improvement in serviceability of transport aircraft.

DRAWING OFFICE OUTLOOK

I am convinced that the proper outlook on maintenance must be instilled into everyone in the drawing office from the start. It is not a thing that can be achieved in five minutes, but is part of a draughtsman's training. It is no substitute to have a maintenance expert in the drawing office, although a sufficiently experienced airline maintenance engineer can be of great value as a consultant. I am a great believer in the old fashioned system of training, that is, two or three years in the works before going into the drawing office. I do not believe that this period can be skipped if a man is to become a competent designer. It is most important that designers and draughtsmen should be in constant touch with the shops and service department so that they may see the troubles which occur in the parts that they have designed.

At one relatively slack period some years ago my firm went so far as to put several of our most senior designers in the shops for three months to work on the assembly of the components that they had designed. I am sure the people concerned would agree that this time was not wasted. Occasional visits to the maintenance shops of the operators is also of great value. There is nothing like personal contact between the designer and the people who are running and maintaining aircraft; second hand information is not the same thing. Also, reports from the service department should be made available to designers and draughtsmen so that they can see what items give trouble in service.

LIAISON WITH OPERATOR DURING DESIGN

If the best results are to be obtained it is of the greatest importance that designers should be in close touch with the engineering and maintenance departments of the airline or airlines for which the machine is being designed. It is not sufficient to rely on some published book of requirements. A large proportion of these are sure to be out of date or do not refer to the problem in hand. There seems to be a certain amount of feeling among maintenance engineers that they are

not consulted during the design stage of an aeroplane. As far as my own firm is concerned it has certainly been our policy for a long time to consult our own service department and operators' engineers throughout the design.

It is important to realise, however, that there are a great many considerations in the design of an aeroplane, most of them conflicting. It is no good having the perfect machine for maintenance which carries no payload. From experience I have found that there are few people who are capable of giving constructive criticism during the early scheme stage of a design. Criticism is of little use to the designer after the aeroplane has flown.

During the design of the Comet we have had a senior maintenance engineer of British Overseas Airways Corporation stationed at Hatfield, who has been available to people in the design office for advice on maintenance features. This scheme has worked well, although it is obviously largely dependent on the personality of the man; also it is important to realise that this function is entirely advisory. The final decision must be the designer's.

DIFFERENCE BETWEEN MILITARY AND CIVIL AIRCRAFT

In this paper I shall talk mainly about civil transport aircraft, but before doing so it might be worth considering for a few moments the differences between the civil transport and the operational military types, from the point of view of maintenance.

The first and most outstanding difference is in the amount of flying done by the two types. A modern civil transport aircraft will probably have to last for 10 years, and fly between 2,000 and 3,000 hours a year, that is a total life of 20,000 to 30,000 hours. The average life of a fighter during the last war was between 40 and 50 hours, whereas the operational fighter or bomber of today, even in peacetime, will probably have a total flying life of no more than 400 to 500 hours. These times do not apply to Transport Command aircraft or to trainers, and probably not to most types used by Coastal Command, which do long periods of patrol.

It is at once evident that the whole problem of design for maintenance presents an entirely different aspect in the two classes of aircraft.

With transport aircraft, the life of components and wear of the aircraft generally become very important. The aim will be to keep the machine flying every day, thus putting a premium on the ability to change components quickly. The military aircraft, however, will spend long periods on the ground. Even in wartime a military aircraft would spend a great deal of its time on the ground between relatively short periods of intense activity.

Facilities for the maintenance of military aircraft, especially under wartime conditions, are much inferior to those available to the civil operator. Servicing often has to be done under appalling conditions. Personnel also, of necessity, are far less skilled because of the enormous expansion of the R.A.F., inevitable in wartime, and to the need to use National Service men in peacetime. It would seem logical, therefore, to cut down to the minimum the amount of maintenance to be done by the squadrons of operational military aircraft. How far this can be achieved is a matter of some doubt. If it were possible to eliminate all maintenance from the squadrons so that the only work done would be refuelling and topping up of the various systems, and routine oiling and greasing, the gain in man power would be great and also, in my opinion, the serviceability of the aircraft.

I believe it should be possible with the modern jet fighter to make the airframe function satisfactorily for say, 100 hours, without any attention other than routine refuelling and greasing. The propeller is eliminated from this class of aircraft and the straightforward pure jet engine is a very reliable power unit, at any rate certainly up to the periods under discussion. There is nothing much that can be done to these engines, they either go on working or the engine is changed, so that the determining factor is likely to be the equipment and components of the aircraft systems. The whole airframe, and particularly instruments and radio sets, has a much easier time in a jet aircraft because of the lack of vibration.

With a new outlook on life testing of components and all items of equipment, it should be possible to make each item capable of functioning for 100 hours or six months, whichever is the less, without attention. Surely it should not be necessary to remove guns from an aircraft every time they are fired. Radio and radar sets give far too

much trouble and are continually having to be removed from the aircraft. This, to my mind, is largely due to such things as soldered connections and terminals with no method of locking; in fact, generally a very low standard of detail design which would not be tolerated in the aircraft structure.

At the end of this 100-hour flying period I would suggest that the machine be sent to a properly equipped and manned workshop for a major overhaul where, as the machine does not have to be on service the next day, more time can be spent in dismantling the structure to get at components for check than could be tolerated in a civil transport aircraft.

What I have in mind is that the components of, for example, the hydraulic system, should run for 100 hours with no attention whatever, other than the filling of the system. While it might not be possible to get at the components of the system for daily maintenance, at a major, say 100 hour overhaul, it may be necessary to remove structural panels from the airframe and also, in order to provide access to the hydraulic units, to remove other items of equipment, all of which might take several days.

With future types of fast military aircraft we shall have very thin wings and slim fuselages and it may be impossible to provide the same degree of accessibility for easy removal of components that we have been used to in the past. I would suggest that much of this equipment can be built-in and, provided that it is properly developed and tested, it should be capable of functioning satisfactorily between major overhauls. To achieve this desirable state of affairs a much higher standard of reliability will be demanded from equipment and systems, particularly from all items of electrical equipment.

More emphasis would probably have to be placed on intensive flying of two or three early production aircraft, if possible under Service conditions, using the equipment in the aircraft as it would be used in actual operating conditions. In other words, guns and rockets, radio and radar, would be used during these tests, as it is well known that an aeroplane can be flown round an aerodrome for months without showing up the troubles which quickly develop as soon as the machine is used under Service conditions.

I realise that the danger of this scheme is that it may tend to produce an inflexible design, one which cannot make use of the latest radar and other military equipment which may be developed during the Service life of the machine. It may not be possible to go as far as I have suggested, but it would appear to be quite possible to produce a fighter in which the main structure of the airframe, including the undercarriage and power plant, hydraulic and basic electrical systems, would function without attention for 100 hours.

DESIGN FEATURES AFFECTING SERVICEABILITY OF TRANSPORT AIRCRAFT

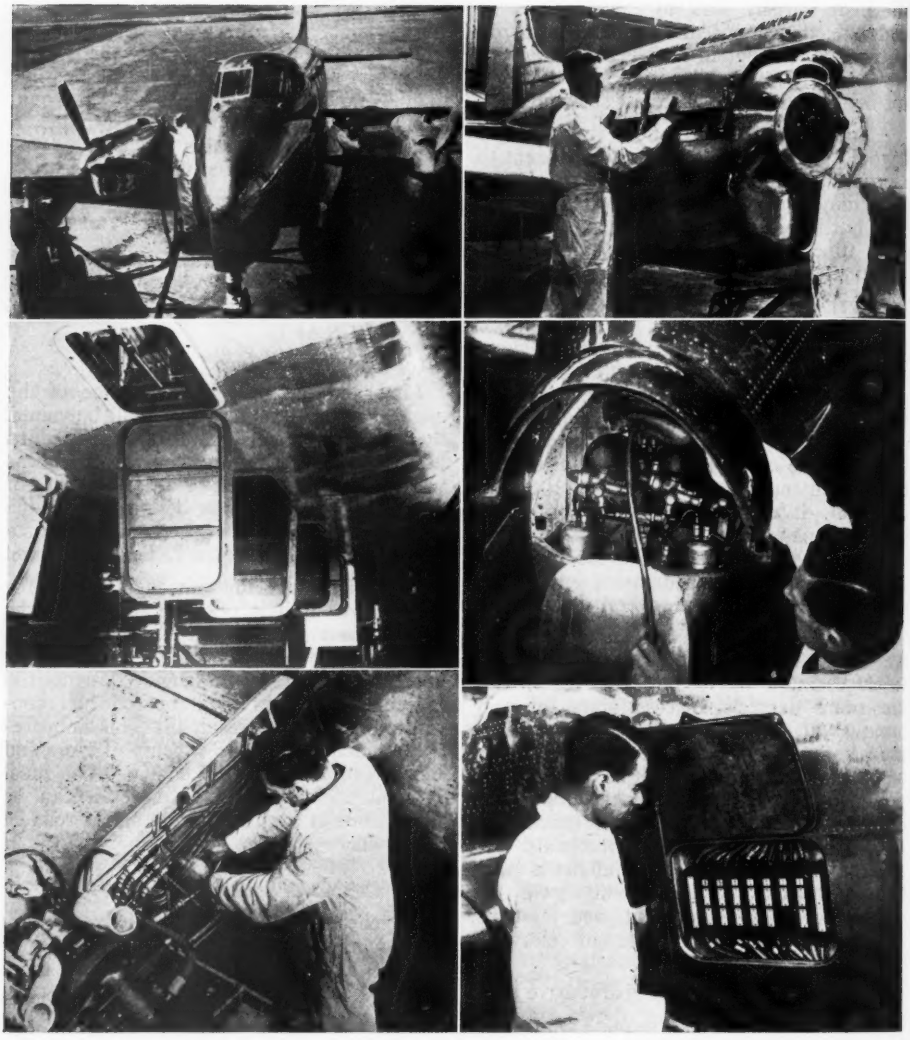
(*a*) *Choice of engines*

First and foremost is the choice of the engine, as the best aeroplane will be ruined by an unreliable engine. This, in general, so far as civil aircraft are concerned, means using an existing engine or a development of an existing engine, or at best a new engine based on considerable past experience of a similar engine and not a radical departure.

It is often said that no engine is fit for civil use until it is obsolete. There is the danger that the aircraft designer, in his natural desire to improve the efficiency of his aeroplane, will press the engine designer too far in such things as improved fuel consumption, with the result that this improvement is achieved at the expense of more and more complexity in the engine. The most efficient engine is no use unless it can be maintained at reasonable cost and is reliable in service.

(*b*) *Layout of machine*

In general a low-wing layout is better from a servicing standpoint than a high wing, since engines and refuelling points are more readily accessible without the use of steps. A large part of the wing and main undercarriage can be reached for inspection and maintenance without having to make use of ladders. The short undercarriage made possible by jet engines helps to achieve this desirable feature of an aeroplane which is low on the ground. The low-wing layout has considerable advantages from the point of view of installation of control cables, hydraulic pipes, electric cables and equipment, and so on, all of which can be run under the cabin floor and be accessible for



Figures 1 to 6 (above) and Fig. 7 (opposite) illustrate the accessibility of the Dove for ease of maintenance, without the use of steps.

Fig. 7.

inspection and maintenance through doors in the underside of the fuselage, without having to disturb cabin upholstery. Also, it obviates the need for maintenance personnel to work in the passenger cabin.

Pressure refuelling, while admittedly adding complications, has a great advantage in that it avoids people climbing on the wings to refuel the aircraft through filler caps on top of the wing, which under bad weather conditions is an unpleasant, and possibly dangerous, operation. Pressure refuelling is particularly necessary for jet transports where the amount of fuel carried is probably double that needed for a piston-engined aircraft.

(*c*) *Unhanded components*

Every effort should be made to avoid "handing" major components, such as undercarriages, brakes, elevators, tailplanes, complete power plants, fuel and oil tanks.

(*d*) *Break down*

The position of service joints in the main structure can be of considerable importance to the operator; my own choice, if possible, is for a wing joint at the side of the fuselage. This allows wings and fuselage to be transported more easily than the more conventional stub wing which is more or less permanently attached to the fuselage. Damage in a bad landing is usually confined to the area round about the main undercarriage. If the undercarriage is attached to a stub wing this may involve removing the stub from the fuselage, which is usually a big job involving a great deal of dismantling of controls, piping, electric cables and main structure. On larger aircraft it may be necessary to put another joint in the wing, approximately half way along the semi-span, to enable a unit of the wing to be handled and transported. To achieve this object a certain amount of weight in wing joints is worth while on civil aircraft. When we get to the very large transport aircraft the question of joints has to be reconsidered because of the impossibility of transporting spare units.

Before the war we had an Albatross which damaged a wing at Tunis. The Albatross had a wooden wing in one piece from wing tip to wing tip, so that although the damage was outboard of the engines a repair had to be made on the spot. A working party was sent out and the repair took something like two months, during which time a valuable aircraft was out of action.

(*e*) *Accessibility—component change*

The modern airline technique is to change the component or item of equipment which has given trouble or has reached its service life. No attempt is made to service the component in position on the aircraft. This obviously means providing good accessibility to items which may have to be changed. Ideally, it should be possible to remove any item of equipment without having first to disturb other structure or piping to obtain access to the item to be removed. It is important that the minimum number of attachment bolts should be used and, if possible, sub-assemblies which can be bench-tested before installation in the aeroplane should be provided. It is desirable to separate routine maintenance and charging points, so that a number of men can work on the machine at the same time without all being crowded into one small space (Figs. 1-7).

With large pressure cabin aircraft, it may be difficult to provide a large number of access doors and it may be better to allocate a part of the underfloor area to an equipment compartment, where the majority of such things as pressure cabin valves, re-circulating fans, electrical equipment, and hydraulic units, can be installed without the need to off-load luggage and remove the linings of baggage compartments to reach these items for adjustment or replacement. This scheme of a separate equipment bay is only attractive if proper access can be provided and a number of men can work at the same time without getting in one another's way. An

additional advantage of such an arrangement is that access to this equipment compartment can be provided in flight through a trap door in the cockpit floor, thus enabling the crew to reach items of equipment in flight.

The cockpit requires great care; only two or three men can work in this area at the same time. Where possible, items of equipment needing adjustment and frequent replacement should not be installed in the cockpit. Hinged instrument boards are a good feature, especially in pressure cabin aircraft where access to the back of the dashboard is difficult.

When all the items of equipment are known it is relatively easy to make a clean cockpit. It is the changes in equipment and radio which are continually being made during the design stage and throughout the life of the aircraft, which often spoil what was to start with, a good cockpit layout.

(f) Complexity

Undoubtedly aeroplanes will get more complicated as time goes on; this has always been so with any form of transport vehicle and will certainly continue, but I suggest it should be a proper, orderly development with no new piece of equipment being used until a real need for it has been established and the cost both in development and extra maintenance assessed and found to be worth while.

Airline operators and air staffs have been far too much inclined to ask for every conceivable piece of complicated automatic equipment, without apparently having given much consideration to its effect on the maintenance of the aircraft. Advice is often taken from scientists who have little appreciation of the difficulties of making equipment really reliable, and who regard any piece of mechanism, however complicated and untried, as merely a piece of "ironmongery," which they conveniently assume will work.

There are indications that the airlines are beginning to realise the need to throw out some of the gadgets. In a recent excellent article, Mr. Koepenich, Chief Engineer of T.W.A., stated that of the total maintenance cost of a modern four-engined aircraft (excluding engine maintenance), 95 per cent. was due to equipment, systems and automatic gadgets, and only 5 per cent. to the basic airframe. A large proportion of the 95 per cent. was accounted for by electrics and electronics.

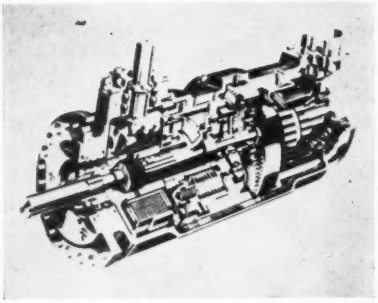


Fig. 8.
An electric actuator.

One of the latest types of transport aircraft to go into service has nearly 900 electric units, such as actuators, solenoids, relays, pressure transmitters, electric motors, and so on, in addition to 10 combustion heaters spread over various parts of the aircraft. It would appear that this sort of over-complication must put the maintenance engineer in an impossible situation. Perhaps the engineering personnel of the airlines have not had enough say when the airlines' requirements have been drawn up for these aircraft.

(g) Remote operation of components

There is no doubt in my mind that the best method of operating anything remotely is by cable or mechanical linkage. Power should only be resorted to where loads are too great for manual operation. It is a temptation to the designer to put in electric actuators, solenoid switches (Fig. 8), and so on. This is the easy way out; it is much more difficult to design good cable runs than to put in a few electric wires. An electric actuator is a complicated, rather fragile, mechanism with limit switches, slipping clutches, and indicator lights to show that it has functioned, and almost needs a second indicator in case the first one fails. A cable control is capable of being used to intermediate positions; it needs no indicator, since the operating lever is its own position indicator. In general once this type of control is properly installed, it needs little maintenance and is a thoroughly reliable method of operation which can be used on vital systems without the chances of failure so often associated with small electric units. We are all familiar with the continual trouble

on many different types of aircraft, with undercarriage lights. Undoubtedly, some of this trouble has been due to bad installation and to the fact that the micro switches have to work, very often, covered in mud. The fact remains that these micro switches have been a continual source of trouble. I believe one of the main reasons has been lack of proper development of the units. They may work well under ideal conditions when perfectly installed, but fall down when required to work under bad conditions.

On the Comet we have gone for mechanical indicators in the cockpit for the main undercarriage and nose wheel. These indicators are operated by cables from the undercarriage radius rod locks. They have been a lot of trouble during the design stage but I believe they will give a completely reliable indication of undercarriage position throughout the life of the aircraft.

The foregoing arguments apply with even greater force to electronics. They are far too attractive on paper to the aircraft designer. There seems to be nothing that cannot be done by a little black box with a few valves in it. Unfortunately, as the design progresses this one small box has a habit of becoming several, much larger and heavier boxes. However, the real trouble starts when the aeroplane gets into service. The recent difficulty with electronic automatic pilots is an example. One is told that in one particular type of automatic pilot, if a valve fails under certain circumstances, it is quite possible for the auto-pilot to put on full rudder, aileron and elevator, all at the same time. This automatic pilot, incidentally, is not of British design.

In my opinion, there is need for a great deal of development in the small electrical equipment designed especially for aircraft. Until recently there were no firms in Great Britain specialising exclusively on aircraft electrical equipment as there were for hydraulic equipment.

Some of the responsibility for the unreliability of electrical equipment must be shared by the aircraft designer, who in the past has pushed the electrical engineer to produce smaller and lighter equipment without enough regard for reliability. We may have to accept a slight penalty in weight to obtain a really serviceable component, provided that weight is not wasted, as so often happens in the design of most items of equipment by the use of brass or steel when duralumin could be used.

It is the easiest thing in the world to make an aeroplane complicated. One is continually faced with the situation of having to add still more complications to an already complex unit to make the original components function. When this state of affairs is reached it is usually worth while starting again, in an endeavour to reach a simpler solution.

An excellent example of equipment becoming too complicated was provided by the cabin blower of the Comet. Originally we intended to have two separate centrifugal blowers driven by pairs of engines on each side of the aircraft. As the design progressed this blower became a three-stage blower running at 30,000 r.p.m. driven by shafts rotating at 7,000 r.p.m. through a free wheel device, so that in the event of one engine failing the drive would be from the remaining engine. The final drive to the blower was through a fluid clutch, which in turn needed its own oil cooler. All this was to be controlled by an electronic box of tricks. Having arrived at all this it became fairly obvious that the thing would never work or, at best, would need a great deal of development and would always be a serious headache to the maintenance engineer. This was the time to sit back and make quite certain that there was no other simpler way of doing the job. The most obvious one seemed to be to tap the main engine blower. There was at that time, and probably still is, a regulation which prohibited tapping the engine blower for cabin pressure. Although this regulation existed, we thought that it was not necessarily correct and since there seemed to be good reasons why such a scheme might work, it was tried out on the test bed and in a Ghost Vampire, tapping the correct amount of air needed for the Comet, with complete success. The whole system is working well in the Comet to date, with a very great gain in simplicity.

Incidentally, this illustrates the folly of attempting to make regulations before enough experience has been gained to know that they are either necessary or feasible.

Another fruitful source of complication is the gentleman who says "What happens if . . . ." In other words, who tries to cover every conceivable likely and unlikely type of failure and endeavours to improve the situation by the addition of still another piece

of equipment to cover the case of failure in the original unit, instead of developing and testing properly the first unit and so ensuring that it will not fail. The result is that we arrive at something which is so elaborate that although it is supposed to cope with every possible type of failure, because of its complexity it is almost bound to fail.

This type of thing is particularly prone to happen when some new item of equipment is being introduced, on which there is no long background of experience on which to rely, such as power-operated controls. This sort of decision is perhaps one of the most difficult that a designer has to make, whether to duplicate or even triplicate in case of a failure, and so make failure much more likely; or whether to make the basic scheme thoroughly reliable by development, so that it will not fail.

In addition to the maintenance difficulties caused by over-complicated equipment, there is the actual danger caused by failure of these units. For example, there is the case of a civil air liner which was taking off on full load, at night, in bad weather, when soon after take-off a fire-warning light flashed, indicating a fire in a baggage compartment under the floor. The pilot turned back and made an emergency landing at a weight considerably above his normal maximum landing weight, in very bad conditions, only to find that there was no fire, but an electrical fault in the indicating circuit. Had provision been made in the aircraft for access in flight to the luggage compartment it might have been possible for the crew to have made sure that there was, in fact, a fire before making an emergency landing. Until such time as really reliable fire and smoke detection devices are available, it would seem preferable to make use of the human nose which, after all, is not a bad smoke detector.

TESTING

If the future civil transport aircraft is going to be made into a reliable vehicle and one that can be maintained at a reasonable cost, it seems to me that we shall have to do a great deal more testing of systems and components during the design stage of the machine.

System testing

The aim should be to reproduce on the ground the complete system with all pipe and cable runs of the correct length and disposition. As far as possible, operating conditions should be simulated.

It may be impossible to put a complete system rig in a cold chamber, but it is usually possible to test sections of the system and individual components under cold conditions.

Every conceivable type of failure should be simulated on this test rig. In this way it should be possible to eliminate, during the time that the first aircraft is being built, the majority of the troubles which would have occurred in service if this testing had not been done.

An example of what can be done in this way is provided by the Dove pneumatic system for undercarriage and flap operation and brakes. We had no experience of pneumatic operation, so a rig was produced with the main undercarriage and nose wheel using the actual parts. Flap jacks were loaded to give the correct hinge moments, all pipe lines were the correct length, air compressors were driven by small motors, and the whole rig was functioned in a cold chamber. The first results were entirely unsatisfactory and many of the components which had been supplied to us as suitable for operation at low temperatures were found to be quite useless at $-20°$ C. After considerable development we were able to produce a system for the aircraft which has been reasonably trouble-free.

Component testing

Although it is probably not possible to represent completely flight conditions on a ground test, it is undoubtedly true that a great deal more can be done than has been the practice in the past.

In my view a large part of the responsibility for life testing of components rests with the equipment suppliers. It is becoming increasingly necessary for the aircraft designer to be in very close touch with the equipment supplier and to give him as good an idea as possible of the conditions under which the equipment will have to function, and to help to lay down a testing schedule which is as representative as possible of operating conditions. The days when the prototype aeroplane was used as the guinea pig by the manufacturers of equipment are past. The cost of the modern transport aircraft is so great that neither the manufacturer nor the operator can afford to have

a machine out of action because some small item of equipment has not been properly developed. I look forward in the very near future to the time when a designer will refuse to fit a piece of equipment to a new aircraft unless the component manufacturer is prepared to guarantee a reasonable life for that component. The operator may have to face some increase in the price of equipment to cover this testing but, in my view, he will be willing to do so if he can be sure that, in effect, he is buying reliability.

COMPARISON BETWEEN PISTON-ENGINED AND JET TRANSPORTS

If we assume that many of the future civil transport aircraft will be powered with jet engines or propeller-turbines, it might be of interest to try to compare these aircraft, from the maintenance standpoint, with the present breed of large civil aircraft on which the airlines of the world depend for their services now.

The most striking difference lies in the power plant and its installation. It seems to be generally agreed that the power plant of the present piston-engined transport aircraft accounts for between 50 and 70 per cent. of the total maintenance cost, depending on the type of engine and the complication of its installation. It is interesting to compare a jet engine installation with the piston engine installation in the latest large passenger aircraft to be put into service, which may be taken as representative of the latest development of the piston engine power plant.

Engines

This power plant consists of a 28-cylinder 4-row air cooled engine with 7 magnetos an engine. These magnetos are pressurised from a separate small blower on each engine, presumably so that they will function at altitude. The carburettor is an injection carburettor of considerable complexity. There are 56 valves and 56 plugs an engine. A simple thing like a change of plugs has now become a major operation, with 224 plugs an aircraft, which are by no means easy to get at, considerable removal of cowling and cylinder baffles being necessary.

All this elaborate mechanism is replaced in the jet transport by a simple centrifugal compressor driven by a single stage turbine. There are ten combustion chambers with no moving parts. In fact, the only moving parts in the whole engine, apart from the main compressor and turbine assembly, are those associated with accessories and their drives, and fuel and oil pumps.

Power plant

When we examine the power plant as a whole, apart from the engine, we find an enormous simplification. The following components and systems can be eliminated entirely:—

1. The propeller with its associated
   Constant speed control
   De-icing equipment
   Reversing and braking system
   Automatic feathering device, and
   Propeller synchronising system.
2. Exhaust-driven turbo-blower with its waste gate control
   Inter-cooler radiators with their shutters and controls
   An electronic control for the turbo-blower.
3. Oil tank and oil system including:
   Two oil coolers an engine with their cooling shutters and controls.
4. Engine-cooling gills and controls.
5. Oil dilution system.
6. Ten combustion heaters, eight of which are used for thermal de-icing and two for cabin heating.

With the jet engine, cabin heating and pressurising can be obtained for almost no extra complication by tapping the main engine compressor, and hot air for thermal de-icing of wings and empennage may be taken from the same source, or from the jet tail pipe.

In addition to these systems which are eliminated, there is the gain of a greatly simplified cowling. The jet engine can be mounted direct to the structural ribs of the wing, thus eliminating engine mounting. The whole installation is accessible through large hinged doors in the under surface of the wing. Engine changing is greatly simplified.

Implication on the aircraft

The elimination of so many systems from the power plant has a similar effect in reducing the number of control runs from the cockpit to the engine and the number of electric actuators required, and so on. There is an enormous simplification in the cockpit. It is literally true that power plant controls

of equipment to cover the case of failure in the original unit, instead of developing and testing properly the first unit and so ensuring that it will not fail. The result is that we arrive at something which is so elaborate that although it is supposed to cope with every possible type of failure, because of its complexity it is almost bound to fail.

This type of thing is particularly prone to happen when some new item of equipment is being introduced, on which there is no long background of experience on which to rely, such as power-operated controls. This sort of decision is perhaps one of the most difficult that a designer has to make, whether to duplicate or even triplicate in case of a failure, and so make failure much more likely; or whether to make the basic scheme thoroughly reliable by development, so that it will not fail.

In addition to the maintenance difficulties caused by over-complicated equipment, there is the actual danger caused by failure of these units. For example, there is the case of a civil air liner which was taking off on full load, at night, in bad weather, when soon after take-off a fire-warning light flashed, indicating a fire in a baggage compartment under the floor. The pilot turned back and made an emergency landing at a weight considerably above his normal maximum landing weight, in very bad conditions, only to find that there was no fire, but an electrical fault in the indicating circuit. Had provision been made in the aircraft for access in flight to the luggage compartment it might have been possible for the crew to have made sure that there was, in fact, a fire before making an emergency landing. Until such time as really reliable fire and smoke detection devices are available, it would seem preferable to make use of the human nose which, after all, is not a bad smoke detector.

TESTING

If the future civil transport aircraft is going to be made into a reliable vehicle and one that can be maintained at a reasonable cost, it seems to me that we shall have to do a great deal more testing of systems and components during the design stage of the machine.

System testing

The aim should be to reproduce on the ground the complete system with all pipe and cable runs of the correct length and disposition. As far as possible, operating conditions should be simulated.

It may be impossible to put a complete system rig in a cold chamber, but it is usually possible to test sections of the system and individual components under cold conditions.

Every conceivable type of failure should be simulated on this test rig. In this way it should be possible to eliminate, during the time that the first aircraft is being built, the majority of the troubles which would have occurred in service if this testing had not been done.

An example of what can be done in this way is provided by the Dove pneumatic system for undercarriage and flap operation and brakes. We had no experience of pneumatic operation, so a rig was produced with the main undercarriage and nose wheel using the actual parts. Flap jacks were loaded to give the correct hinge moments, all pipe lines were the correct length, air compressors were driven by small motors, and the whole rig was functioned in a cold chamber. The first results were entirely unsatisfactory and many of the components which had been supplied to us as suitable for operation at low temperatures were found to be quite useless at -20° C. After considerable development we were able to produce a system for the aircraft which has been reasonably trouble-free.

Component testing

Although it is probably not possible to represent completely flight conditions on a ground test, it is undoubtedly true that a great deal more can be done than has been the practice in the past.

In my view a large part of the responsibility for life testing of components rests with the equipment suppliers. It is becoming increasingly necessary for the aircraft designer to be in very close touch with the equipment supplier and to give him as good an idea as possible of the conditions under which the equipment will have to function, and to help to lay down a testing schedule which is as representative as possible of operating conditions. The days when the prototype aeroplane was used as the guinea pig by the manufacturers of equipment are past. The cost of the modern transport aircraft is so great that neither the manufacturer nor the operator can afford to have

a machine out of action because some small item of equipment has not been properly developed. I look forward in the very near future to the time when a designer will refuse to fit a piece of equipment to a new aircraft unless the component manufacturer is prepared to guarantee a reasonable life for that component. The operator may have to face some increase in the price of equipment to cover this testing but, in my view, he will be willing to do so if he can be sure that, in effect, he is buying reliability.

COMPARISON BETWEEN PISTON-ENGINED AND JET TRANSPORTS

If we assume that many of the future civil transport aircraft will be powered with jet engines or propeller-turbines, it might be of interest to try to compare these aircraft, from the maintenance standpoint, with the present breed of large civil aircraft on which the airlines of the world depend for their services now.

The most striking difference lies in the power plant and its installation. It seems to be generally agreed that the power plant of the present piston-engined transport aircraft accounts for between 50 and 70 per cent. of the total maintenance cost, depending on the type of engine and the complication of its installation. It is interesting to compare a jet engine installation with the piston engine installation in the latest large passenger aircraft to be put into service, which may be taken as representative of the latest development of the piston engine power plant.

Engines

This power plant consists of a 28-cylinder 4-row air cooled engine with 7 magnetos an engine. These magnetos are pressurised from a separate small blower on each engine, presumably so that they will function at altitude. The carburettor is an injection carburettor of considerable complexity. There are 56 valves and 56 plugs an engine. A simple thing like a change of plugs has now become a major operation, with 224 plugs an aircraft, which are by no means easy to get at, considerable removal of cowling and cylinder baffles being necessary.

All this elaborate mechanism is replaced in the jet transport by a simple centrifugal compressor driven by a single stage turbine. There are ten combustion chambers with no moving parts. In fact, the only moving parts in the whole engine, apart from the main compressor and turbine assembly, are those associated with accessories and their drives, and fuel and oil pumps.

Power plant

When we examine the power plant as a whole, apart from the engine, we find an enormous simplification. The following components and systems can be eliminated entirely:—

1. The propeller with its associated
   Constant speed control
   De-icing equipment
   Reversing and braking system
   Automatic feathering device, and
   Propeller synchronising system.
2. Exhaust-driven turbo-blower with its waste gate control
   Inter-cooler radiators with their shutters and controls
   An electronic control for the turbo-blower.
3. Oil tank and oil system including:
   Two oil coolers an engine with their cooling shutters and controls.
4. Engine-cooling gills and controls.
5. Oil dilution system.
6. Ten combustion heaters, eight of which are used for thermal de-icing and two for cabin heating.

With the jet engine, cabin heating and pressurising can be obtained for almost no extra complication by tapping the main engine compressor, and hot air for thermal de-icing of wings and empennage may be taken from the same source, or from the jet tail pipe.

In addition to these systems which are eliminated, there is the gain of a greatly simplified cowling. The jet engine can be mounted direct to the structural ribs of the wing, thus eliminating engine mounting. The whole installation is accessible through large hinged doors in the under surface of the wing. Engine changing is greatly simplified.

Implication on the aircraft

The elimination of so many systems from the power plant has a similar effect in reducing the number of control runs from the cockpit to the engine and the number of electric actuators required, and so on. There is an enormous simplification in the cockpit. It is literally true that power plant controls

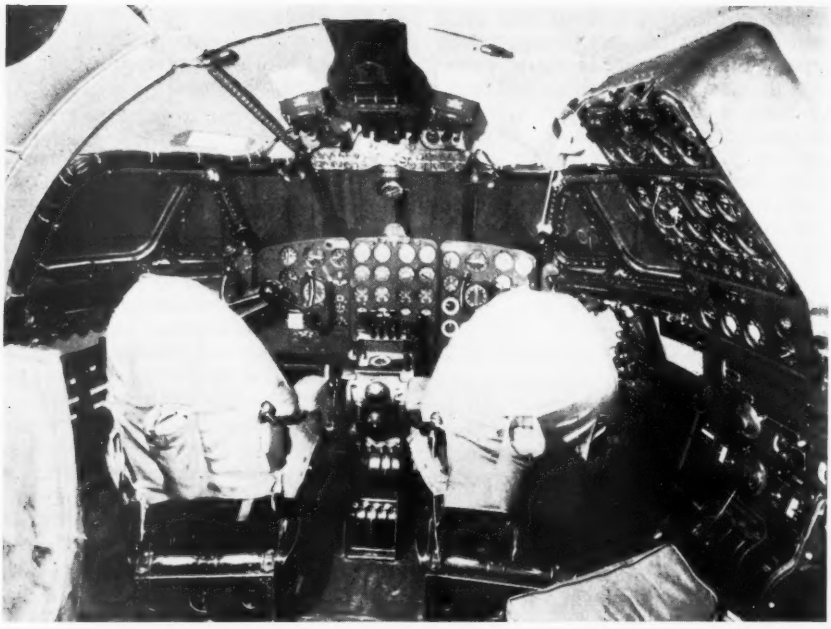


Fig. 9.
The cockpit of the Comet.

for jet engines consist of one throttle lever an engine, plus the usual fuel cocks and fuel pump switches, cabin pressurising controls and fire extinguisher buttons. This in turn leads to a saving in crew. There is no need to carry a separate engineer in the cockpit, which again leads to further simplification. We do not have to provide duplicated throttle and airscrew controls for the engineer, together with a formidable array of instruments and switches, as is the case in a modern piston-engined aircraft (Fig. 9).

Vibration

It is undoubtedly true that the whole aircraft, and particularly the power plant, has a much easier time with a jet or propeller-turbine installation than with a piston engine, due to lack of vibration. This lack of vibration and, in the case of the pure jet machine, the lack of buffet from propeller slipstream, has shown up on the Comet in a greatly reduced amount of routine maintenance needed to keep the aircraft flying.

We have had an excellent example of this effect with the Vampire. The details of the Vampire engine installation are exactly as they were first designed. This is most certainly not true of the piston engine, where continual strengthening and modification of engine installation details is necessary because of fatigue failures due to engine vibration.

Propeller turbines

The simpler types of propeller-driving gas turbine engine, particularly the centrifugal type, are very little more complicated than the pure jet, although the addition of a propeller and its gearing must always be an added complication. It does appear, however, that there is some danger of losing this basic simplicity with some of the larger coupled propeller-turbines which are at present being developed, with their thousands of small blades and multi-stage turbine wheels, complicated gearing and contra-rotating propellers. While this may be necessary in order to achieve the best possible fuel consumption, and may be justified for long-range military aircraft, they may well turn out to be more difficult to maintain than some of the piston engines at present being used.

CONCLUSION

It seems to me that the latest civil transport aircraft have been allowed to become too elaborate, partly due to the demands of the operator and partly to the frightful complexity of the modern high-powered piston engine. Unless something is done to check this ever-increasing complication, it looks as if our future civil transport aircraft will spend more and more of their life on the ground and, in any case, will most certainly not be run at a profit.

The best hope for the future seems to lie in simpler aircraft with reliable and well tested equipment and above all, in the use of a robust and simple gas turbine engine, provided that it is not allowed to follow the piston engine and lose too much of its original simplicity.

DISCUSSION

G. R. Edwards (Chief Designer, Vickers-Armstrongs (Weybridge) Ltd., *Fellow*): He agreed that designers and draughtsmen should have the maintenance problem instilled into them from the beginning, and also on the value of consultation with representatives of the operators during the design stages of the aircraft, but the final decision must rest with the designer, because he had finally to put things right if they had gone wrong. The complexity which had given rise to so much trouble, particularly in piston-engined aircraft, had been due largely to the operators trying to get too much "fanciness" into the machines—doubtful devices such as automatic feathering and the like, and the craze for "automaticity." Such features might have been all right during the war, when aeroplanes were being flown by pilots who had not received very much training; but nowadays they were entitled to assume that a pilot was well trained and experienced, and he imagined that a pilot would be a lot better off if he knew that he himself was doing something to produce a given result, rather than that something in the background was producing that result. A pilot might be more worried because he was wondering whether the automatic item was really working than he would be if it were not there at all.

Undoubtedly for years British electrics had been rather shocking, mainly because, he believed, the Aircraft Industry was being supplied with components which were of motor car standard, but aviation electrical equipment in Great Britain had become a lot better during the past few years. It was being designed by people who specialised in aviation electrical equipment, and that practice was showing dividends. The efficiency of those products was much higher than it had been formerly; and he was beginning to agree with the fashion of using electric actuators for such things as fuel cocks, particularly on pressure cabin aircraft.

In the early days of the war he had had some experience of building and maintaining aeroplanes with pressure cabins, working at a pressure differential of 7½ lb., and it was difficult to keep the rods and cables running through the cabin walls in good working order, with the mechanical rubber seal that was used. But his experience with actuators on a pressure cabin aeroplane had been quite good.

The electronics situation was rather different, and he agreed whole-heartedly with Mr. Bishop's remarks about them. In America they had gone to extremes with electronics. They had applied them to their propeller-turbine control. The British engine designers had managed to get a single lever control with the aid of a rod between the fuel flow unit and the constant speed unit, which seemed to provide all the inter-connecting that was required. In America they used an electronic coupling in a fairly large box. He believed that situation had come about largely because a designer there had flown an aeroplane in which the controls were not inter-connected; unfortunately that designer knew a bit about electronics, and as a result the Industry there had been "landed" with electronic controls.

One way to avoid a lot of trouble when trying to fit a piece of apparatus into an aeroplane was to endeavour to wear it out before it was fitted into its place! To work the thing about 10,000 times—that seemed a good figure—and to throw in sand and so on seemed to be a fairly certain way of finding out whether or not it would continue to function for about 50 hours when it was fitted into the prototype machine!

It was pleasing to be able to report that approaches which had been made recently by his Company to the equipment manufacturers, about the extent to which they would be prepared to guarantee their own equipment, had brought forth a rather refreshing change of front from that to which the Industry had been accustomed in the past. They had offered guarantees over lengths of time which he considered were promising. He did not suggest that those periods were anywhere near the length they ought to be, but they at least held out hope.

He could not agree more with Mr. Bishop about turbine engines. If the percentage of direct operating costs which covered the power plant and propeller and aeroplane were worked out on the current S.B.A.C. formula it came to 35 per cent. of the direct costs. If that could be reduced by, say, 40 per cent. it would be equivalent to the revenue from about half a ton extra payload on a relatively small twin-engined aeroplane. The financial gain arising from improved maintenance was very high, and in addition there would be a big saving in indirect costs.

He agreed that the propellers on some large propeller turbines were getting too big. On some American aircraft there had been some painful experiences of what could happen with big propellers, because the air loading on one blade was not the same as on another; they were getting to a state of aerodynamic out-of-balance which seemed inseparable from the big propellers, because hollow steel blades seemed inseparable from big propellers. The blades developed cracks, so that every other day it became necessary to take off the blades in order to see how far the cracks had developed.

S. Camm (Chief Designer, Hawker Aircraft Ltd., *Fellow*): He was sometimes very much irritated because there seemed to be an impression that design offices gave little thought to maintenance during the processes of design; that was far from true. He agreed that a great deal of complication was due to equipment and automatic gadgetry; unfortunately, while the designer of civil aeroplanes might have some control over the equipment, that was certainly not so for the military aircraft designer.

With the small modern two-seater fighter complication would tend to increase, because the one vital thing about that class of aircraft was the factor of performance; therefore, he strongly supported the suggestion that components of the hydraulic and electrical class, as well as aircraft details, should be designed and tested to ensure that they would run for at least 100 hours without requiring any attention other than the periodic filling of the systems.

To fly the first two or three early production aircraft for extended periods under service conditions would undoubtedly be of value, although his experience was that, for some reason, the defects required time to develop and they wanted to avoid the disturbance to production which resulted from a large number of modifications.

One odd thing about maintenance and defects was that the prototype never seemed to have the troubles which were subsequently met with in production. Often a slight shade of difference in the methods used in making the production and the experimental aircraft seemed to be responsible.

Again, it was noticeable that results varied widely with different squadrons, and that seemed to indicate that the standard of maintenance might influence results more than was thought to be the case.

He fully agreed with Mr. Bishop that the best method of operating anything remotely was by cable or mechanical linkage but with a modern single-seater fighter, where the engine was buried in the fuselage, there was insufficient room in which to provide direct control. That difficulty could be overcome by increasing the fuselage diameter, but that would reduce performance.

A good example of the result of the attitude " what happens if . . . ." was fighter aircraft, where two generators were required. Surely it was not impossible to make the one generator more reliable?

As to the difficulties of designing for maintenance, they should take a calm and dispassionate glance at the average Appendix A and think of incorporating everything contained there; then think of a blank sheet of paper and of a fighter flying fifteen months hence!

N. E. Rowe (British European Airways, *Fellow*): He supposed most of them thought of good maintenance as ensuring trouble-free service; that description was roughly accurate, but its implications were probably much more than might be construed into that simple phrase.

There was what might be called the random failure, *i.e.* the sort of thing that happened in a completely unplanned way; it

did not make itself known during normal inspections, but it happened within what was stated to be the life of the part concerned. It was the random failure which gave a great deal of trouble in airline operation, and was undoubtedly one of those factors that tended to increase the size of fleets necessary for a given job of transportation.

The fact that conditions of operation had not been simulated in tests in the past was at the root of the difficulties they continued to experience with equipment. One of their problems now was to attempt to determine a technique of testing in the laboratory, or on the ground, which would enable them to obtain the results that would be obtained in flight in a given time.

Vibration, dust, variations of temperature that occurred in flight, and humidity, were probably the four main factors which gave rise to a great deal of the unserviceability of equipment and components, and which must be brought into the tests if they were to eliminate random unserviceability by forecasting the lives of the parts separately before the aircraft went into operation.

The British European Airways Corporation had obtained a contract from the Ministry of Supply wherein they were attempting to develop that technique in relation to the Ambassador. They had selected a number of parts for trial in the laboratory and were manufacturing test rigs with the co-operation of the firm, the Ministry and all concerned. They had made a vibration survey of the aircraft; he did not know if that were the first to be made in Great Britain, but it was obviously the necessary starting point. Knowing the vibration state of the aircraft at the points where the components were situated, they intended to feed into the test rigs vibration conditions, variations of temperature, dust and humidity conditions, to simulate as closely as possible the conditions on a representative stage, or representative stages, of routes along which the aircraft would operate. Whether or not they would be successful remained to be seen; but he had high hopes of at least a percentage of success.

It should be possible to maintain fighter aircraft efficiently by servicing only once in 100 hours, apart from topping up, and so on. The interval could probably be extended further if they pre-determined the changing conditions in operation and the life of the parts under those conditions. It seemed that the absence of vibration in jet-propelled aircraft might mean that the lives of parts could be very much prolonged, unless other factors came in. Had Mr. Bishop any evidence of the effect of high frequency vibrations, such as might be due to gunfire, and so on, on the wear which might occur in very small parts or small components?

Had Mr. Bishop noted any ill effects of dust, especially in the turbine engine, during the operation of the Comet or of fighters?

In operating helicopters it was hoped to start from the outset with " sealed servicing," which implemented the conception of the pre-determined lives of parts and components and the changing of them when they had reached those pre-determined stages. That might sound optimistic, but he felt there was a chance of getting a long way towards the 100 per cent. determination of lives. That would make a very real contribution to the reduction, not only of cost, but also of man power. The result of good maintenance should be low cost, not only in money, but in time, for the latter affected so much the man power required and the possible utilisation of the aircraft.

Air-Marshal Sir Victor Goddard (Air Member, Technical Services, *Assoc. Fellow*): He was in general agreement with Mr. Bishop and subsequent speakers, including the statements that electrics were getting better and were not getting better; he believed they were both true statements.

One remark in the paper which would encourage particularly the R.A.F., as well as others who were dealing with aircraft, was to the effect that it was folly to attempt to make regulations before enough experience had been gained to know that they were either necessary or feasible. In the R.A.F. they appreciated that, and indeed they had made rapid and quite considerable strides in the direction of refraining from telling people what they must and must not do when higher authorities themselves did not really know; those concerned would get to know very soon, when they had had opportunities to learn by experience. The Air Ministry sought to give technical guidance and warning on the basis of past experience, but not to inhibit initiative.

He wondered how far it was wise to dispense with duplication. The elimination of secondary safety equipment before absolute reliability was achieved would result in a reversion to the " nosey parker "

business, to see how things were getting on, and that in turn would result sometimes in those things being replaced in such a way that they would not get on for very much longer!

D. Mowrer (Boeing Airplane Corporation): Probably all airframe manufacturers had devised one scheme or another for familiarising their designers with aeroplane operating practices and problems. Those manufacturers who had not taken design for maintenance into serious consideration would not survive long in a business as highly competitive as the Aircraft Industry.

At the Boeing Airplane Corporation the Service Department was an integral part of the Engineering Division and was staffed with graduate engineers, most of whom had aeroplane design experience. It was Boeing policy to have as many design engineers as possible work for at least a year or two in the Service Department in order to give those men experience in dealing with aeroplane operating problems.

A senior service engineer was assigned to each design project to act in an advisory capacity on maintenance items. The Service Department also kept the design projects advised of all trouble reports received from field activities.

While proper design for maintenance was very important for the reduction of aeroplane operating costs, he believed that more attention should also be given to other factors which had equally important effects on maintenance costs. There had been rapid developments in aeroplane design during the past ten years, but he wondered if maintenance practices and procedures had kept pace with aeroplane design.

For example, there was established in the United States by the Civil Aeronautics Authority a schedule of maximum overhaul times for each transport aeroplane. It was a sort of tradition to tag each component of an aeroplane with a number which represented its service life in terms of aeroplane flight hours. For example, when an aeroplane completed 200 flight hours, all items tagged with a service life of 200 hours were removed for overhaul. It seemed to him the result was that countless items which operated perfectly satisfactorily were removed and overhauled unnecessarily, just because of arbitrary numbers on a chart. In many cases, this practice served only to reduce the service life of a component due to the extra wear and tear incurred by unnecessary handling. He favoured what was called "On Condition" maintenance and believed that many aeroplane components should be left alone until something was actually the matter with them.

A great deal of effort had been expended on the Boeing Stratocruiser to obtain as reasonable a schedule as possible of C.A.A. approved maximum overhaul periods. They were particularly anxious to avoid an airframe structure overhaul period. Some aeroplanes were tagged with a strange thing called an "8,000 hour major overhaul." Apparently this meant that after 8,000 hours of flight time the aeroplane was put in a hangar where several days were spent more or less dismantling and reassembling it. Instead of this a structural inspection procedure on a "fleet wide" sampling basis was worked out for the Stratocruisers. This approach was considered to be more effective and more economical than the traditional structural overhaul period.

He thought that where it became necessary to establish an overhaul period for a piece of equipment, the service life should not always be based on aeroplane flight time. For example, a combustion heater might be due for overhaul after 500 hours of operation. The firing time of the heater would have very little relation to aeroplane flight time; by putting a timer on this heater perhaps it could be overhauled only about once every 1,500 flight hours during winter operation and perhaps about once every 3,000 flight hours during summer operation. In other words, the cost of several overhauls could be saved by basing the overhaul period on heater time, instead of flight time.

A much too prevalent and costly maintenance practice was the removal and replacement of perfectly good components of an aeroplane system because of faulty diagnosis, or no diagnosis of the trouble with the system. Too often corrective action was by trial and error. Various pieces of equipment in the mal-functioning system were replaced in the hope that one of the items replaced held the cause of the trouble. With some airlines perfectly serviceable equipment removed in error must go through the complete overhaul, inspection and functional test procedure before it could be re-installed.

More work should be done to establish efficient functional checking and "trouble-shooting" procedures. More should be done by the designer; design for maintenance

should include design for ease in functional testing and "trouble shooting." More aeroplane systems and components of systems should be designed so that, in effect, they could be bench-checked without removal from the aeroplane.

There were many factors affecting maintenance costs, but in his opinion much could be done to reduce them by modernising some of the out-dated aeroplane maintenance practices, as well as by fostering design for maintenance.

S. Scott Hall (D.G. Technical Development (Air) Ministry of Supply, *Fellow*): The Ministry of Supply were very interested in the problem of design for maintenance or, as they preferred to call it, "design for reliability," as distinct from "design for servicing." They regarded reliability and servicing as being two complementary things, and had discarded the use of the term "maintenance" because "reliability" was considered a better description.

Their interest in the subject had been encouraged by several authorities, principally the Royal Navy; there the question of reliability was perhaps at its most acute. A number of aircraft were housed in a floating hangar of very small dimensions, in which there was extreme difficulty in getting around the aircraft in order to service them, and the demand for reliability was one which had to be given precedence over others. When it became a question of compromise between reliability and performance he believed it would not be wrong to say that the Royal Navy had more interest in reliability than had even the R.A.F.

Mr. Rowe had mentioned the contract which the Ministry of Supply had let for work in connection with the Ambassadors, work on a civil aircraft where the conditions of operation were very different from those applying in the Services. Work was also going on in connection with the military problem. It had been concluded that the environment of a failure was a much more critical factor in military operations, where the conditions of operation of the same type of aircraft often varied widely; they were studying particularly the environmental conditions in which any failures occurred, with emphasis on those minor sources of unserviceability which never got so far as the Form 1022. He believed that a great deal would come out of that work, and that the results would be of vital benefit to the reliability of military aircraft.

He had understood Mr. Bishop to say that they could not do anything by having maintenance experts in the drawing office. Surely Mr. Bishop would regard it as of value to have in his drawing office people who possessed first-hand knowledge of the conditions under which the aircraft would have to operate? It had been suggested that if suitable Engineer Officers from the Services could be stationed in design offices, they would give great help towards looking after the aspects of design which influenced reliability.

Mr. Bishop had referred to regulations and in particular, the regulation prohibiting the tapping of the engine blower for cabin pressure. Regulations were not issued without a reason. He had not had time to look up all the papers, but to the best of his recollection the engine manufacturers had stated emphatically that if their compressors were tapped for purposes such as pressurising cabins, the essential matching between compressor and turbine would be destroyed. Furthermore, they wanted freedom to put de-icing and other fluids through their engines which they would not have if the crew and passengers had to breathe air drawn in this way from the compressor. That was why the regulation had been issued. He did not think that it was even a hard and fast requirement, and no doubt it would be withdrawn as the result of the success of the de Havilland Company with the Comet.

C. G. A. Woodford (*Assoc. Fellow*): A good deal was being done to raise continually the standard of performance and the reliability of all electrical equipment for aircraft. During the past few years he had been privileged to represent the Society and the Institution of Electrical Engineers on the joint committee work that was being undertaken in connection with the British Standards Institution. In recent weeks the first draft of Specification G100 (as it would be known) had been circulated around the industries for comment, covering the general requirements for electrical instruments and apparatus for all types of civil aircraft, most of the provisions in it being common with most of the requirements for military aircraft. The first series of comments, which had been enlightened and helpful in many ways, had been received and the Committee was actively engaged in reviewing them. Quite a lot of work had been put into the draft specification, and he felt sure it would go a long way, with other

specifications accompanying it on particular items—generators, actuators, and so forth—towards the building up of a unique and exceptionally useful work of reference, available in Great Britain and throughout the world.

Just as nations were said to have the Governments they deserved, perhaps aircraft firms and groups received the equipment, and particularly electrical equipment, that they deserved. It was largely a matter of the amount of money they were prepared to spend in getting the right interests at the right sort of level to handle those questions. There was a need for a front-line, independent expert at the disposal of the aircraft firms and groups, to undertake on their behalf, and on behalf of their customers, a study of equipment; to form a link with the equipment manufacturers. Often equipment was designed and offered too late to be adequately treated and tested before it reached the aircraft, and too many changes were asked for in the course of its life. He knew of only one leading aircraft firm in Great Britain which employed a first class electrical engineer to deal with those matters. He supposed that a firm which did business to the extent of millions of pounds in aircraft and their equipment, and complained that they were not supplied with the right electrical equipment, would also complain if they were asked to spend £2,000 a year to employ the right sort of man to ensure that they received the right equipment, a man to serve as consultant. It might help if, say, six firms in a group contributed a few hundred pounds each per annum and appointed a qualified man to represent them as a group.

In the small aeroplane there might be a distinct advantage in the use of a cable wire as against electrical actuation or operation. In large aircraft the situation was very different; in a large aeroplane, for example whereas the average weight of the manual equipment was 11 lb. a fuel cock, the electrical equipment weighed 2 lb. a fuel cock.

It was often not easy to maintain manual controls in service. Flexure due to temperature and structural changes was very considerable. He did not think anybody in their homes would use nowadays the old type of bell pull, with its springs and gadgets, and its cables negotiating corners, where electric bells could be used. Again, how many people would use a speaking tube rather than a telephone?

Air Vice-Marshal C. W. Weedon (Director-General Technical Services (2), R.A.F.): He was very glad to see the interest that was now being taken in the two allied questions of design for reliability and design for easy servicing. The emphasis was on the first requirement as, if they could have reliable aircraft, design for easy servicing was relatively of small importance.

It would be a tremendous step forward if the Royal Air Force could receive, from the manufacturer, an aircraft which could be relied upon for 100 hours' flying or for six months on the ground, without any attention whatsoever, apart from filling up and pumping up the tyres. He thought they would be appalled to know that to-day they were averaging something like one and a half defects for every hour of flying. Some of the results of this high defect rate were:—

(*a*) Half the technical personnel were employed on pulling assemblies apart with a well justified fear that a random defect might be revealed.

(*b*) A swollen establishment of aircraft in order to cater for the large number undergoing rectification or servicing.

(*c*) The provision of an enormous range of spares to make good any defect that was found.

(*d*) A complex system of training which did not fit in with the idea of the National Service airman of eighteen months' service.

There were three ways in which they, the users, hoped to help the Industry.

First, there was the question of the early teething troubles which they always seemed to experience, to a larger or less extent, with every new type of aircraft accepted into the Royal Air Force. In the past they had not got in nearly enough flying on the first batch of deliveries. As a result, troubles were not found until the aircraft had been in service for a considerable time, and by then, possibly hundreds of aircraft had rolled off the production line, only to require extensive modifications at a later date.

Although they had not reached agreement with everybody concerned, he hoped it would be possible for the first batch of production aircraft to be sent to one of the Home Commands where really intensive flying could be done. He would like to see something like

1,000 hours in the first three or four months, and during this time every defect found, and every spare used, accurately recorded. In this way he hoped that early modification action could be taken before many aircraft had been delivered. At the same time, they would get most useful information to enable them to review their guesses made when they did the initial provisioning of the spares required. Personally, he was strongly in favour of this intensive flying being done in the Service, where the aircraft could be flown by normal pilots and maintained by normal tradesmen, of whom the National Service airman formed the greater percentage. They would need to co-operate closely with the Aircraft Industry and he hoped if those experiments were agreed, the firm concerned would send an observer to keep an eye on the trials.

Secondly, the users could help the Industry, by the adoption of a sound method of maintenance. In the past, and especially during the war, they were open to criticism in that they pulled assemblies apart just to see whether they were all right. He would like to see their maintenance confined to:—

(*a*) replacement of components which had been given a definite life,

(*b*) the storing up of maintenance by application of oil or grease, etc.

The third, and possibly the most important, way in which they could help the Industry was to record accurately every defect which occurred, whether discovered on the ground or in the air. In the past, it was true to say that only a minority of their troubles and defects had been reported and the information passed on to the Industry. In the next few months they hoped to set up a system whereby every single defect was recorded, no matter how minor its nature. As an example, every year they replaced thousands of radio valves, any one of which might lead to an abortive sorti. By recording every replacement, they hoped to be able, not only to "life" that particular valve, but to draw attention to those valves which continually failed, in order that they could be re-designed.

He hoped that Mr. Bishop did not intend to imply that they could expect fighter aircraft designed to last 40 or 50 hours—their probable life in war. They had to fly these aircraft in peace time, and he thought the problem of design for maintenance for the Royal Air Force was not really very different from that required for civil aircraft.

D. W. Richardson (Society of Licensed Aircraft Engineers, *Assoc. Fellow*): The statement that 25-40 per cent. of total operating costs were attributable to maintenance could be somewhat misleading. Assuming that the figures were based on S.B.A.C. costing formulæ, the term "maintenance" included inspection, servicing and overhaul of airframes and their equipment. Routine cleaning was a passenger service and, as such, was regarded as an operating cost. Furthermore, taking an average labour rate of 3s. 4d. an hour, a 200 per cent. charge upon that was allowed for workshop overheads, and that represented a figure which would remain reasonably static, whether the workshops and equipment were used frequently or otherwise.

A scheme which allowed prospective designers to spend a period of two or three years in the workshops would be excellent in every way. It would be of even greater ultimate value if the time could be either altered or extended to allow those individuals to gain practical maintenance experience, because the dismantling and servicing of the modern complex aircraft presented a very different picture from that which they saw in the progressive stage build-up developed for efficient production.

He was not quite sure of the implications of the remarks that "It is not sufficient to rely on some published book of requirements" and that a large proportion of these would be out-of-date or would not refer to the matter in hand. The only such publication of which he was aware, in so far as civil aviation was concerned, was "British Civil Airworthiness Requirements," which were compiled in a deliberately broad sense, purely with the object of allowing designers ample latitude and flexibility for development. In that they performed a most valuable function because they were based upon an overall study of design and operational problems, experienced not only in the United Kingdom, but throughout the world; thus they offered a mass of invaluable information which otherwise would be denied to the individual.

Would Mr. Bishop expand his theory that the best method of remote operation was by mechanical means, particularly in the light of the difficulties attendant upon such a precept when considering the sealing of pressurised compartments, wing flexure, weight penalty, the cumulative effects of wear at fulcrum points and the resultant amplification of

maintenance and inspection duties at prospective sites of wear and lubrication, and so forth.

He fully agreed with the desire to find components the lives of which would be guaranteed to the aircraft manufacturers, but was it entirely due to the component manufacturers that such components were not yet in existence? Was it not possible that the aircraft designer rather tended to hold back development by demanding specialised equipment for various purposes, and did not allow sufficient time for development before it was put into service? It was recognised that the designer was cursed with the permanent and unwelcome attentions of the weight and space "bogeys," and it would seem that the difficulties of both parties must be accepted as something which, while allowing ample scope for improvement, did not offer great opportunities for complete alleviation, at least for a long time to come.

He felt strongly that any attempt at the present stage to "bury" operating components, from pure design considerations alone, could only result in the production of an aircraft which would present servicing "headaches" of monumental proportions.

W. G. Bushell (*Assoc. Fellow*) *contributed*: He had always considered that maintenance troubles derived from five features which affected the operation of aircraft. They were essentially:—

(*a*) The troubles due to corrosion or those which commonly resulted from ageing of components (in the widest sense) including all materials used. If they could guarantee that no corrosion or deterioration of materials ever took place in aircraft the amount of inspection necessary could be reduced by more than 50 per cent.

(*b*) The troubles due to parts being highly stressed in use, due to some form of mishandling. If it were possible to install suitable recording strain gauges on all parts of an aircraft likely to be over-stressed in flight, landing, or taxiing, a simple check on a recording board would again dispense with many hours of inspection.

(*c*) Weaknesses in design, which produced failures and raised the need for "Design for Reliability" and "Sealed Maintenance."

Errors in design which involved repairs on the airfield (illustrated in S.B.A.C. Design Information Bulletins).

The damage and unserviceability caused by too much accessibility being provided for dirt and water but not enough for the maintenance engineer, raising the need for "Design for Servicing."

(*d*) Production defects which caused difficulties for the maintenance engineer, namely, faulty materials and workmanship. Also, the delays resulting through insufficient provisioning of replacement parts.

(*e*) Faulty diagnosis of defects by flying and maintenance crews, often due to insufficiency of published information relating to this "art."

Many of those points might be controversial, but something on those lines from such an experienced designer as the author would have introduced the subject on a broader basis.

He had been particularly interested in Mr. Bishop's suggested design for deleting maintenance for 100 hours flying or six months between overhauls. He doubted if the Royal Air Force or Royal Navy could entertain such a scheme, but for experimental flying this achievement would be a great benefit due to the greater cost of a lost flying opportunity. Already it was partly applied at his particular airfield where they employed a large variety of aircraft for experimental purposes. They worked to an overhaul basis at six to eight months, or 100 to 120 flying hours. They had dispensed with daily inspections but were obliged to do regular weekly inspections and repairs because defects occurred, on an average, every fourth flight. He believed, if it were necessary, that many of their aircraft could safely and economically achieve 150 hours or more between overhaul. Calendar time, however, was more important to them, and sometimes the limiting factor for their work was the number of flights.

For overhauls they gave each aircraft a Nuisance Factor and the higher its value the more labour and time were consumed in the servicing of the aircraft. It must be emphasised, when considering this Nuisance Factor, that it was this and this alone which determined the degree of serviceability of a fleet of aircraft. Aircraft in general could maintain a state of serviceability of between 40 to 80 per cent. according to their Nuisance Factor. For example, it had been found for

many years on his airfield that, in general, a four-engined bomber was 3.5 times the nuisance of a single-engined fighter. For aircraft in the Flights, as distinct from those being worked on in the hangars, the Nuisance Factor was approximately the same, but there were wider extremes. In fact, four-engined aircraft sometimes warranted a lower Nuisance Factor than certain twin-engined aircraft. Nuisance Factors for the components of the aircraft had also remained fairly constant for the past few years; the results for the previous twelve months on the airfield being:—

	N.F.		N.F.
Piston engines and accessories ...	4.0	Alighting gear (including micro-switches)	1.6
Fuel, oil and coolant systems	1.6	Hydraulics and pneumatics ...	1.4
Propellers, and C.S.Us.	0.8		
	6.4		3.0
Structural	2.9	Electrical	1.6
Wings and control surfaces	1 0	Instruments ...	1.0
		Radio	1.6
	3.9		4.2

Those defects which arose just prior to take-off were not emphasised in those figures, nor did the Nuisance Factors given apply to overhauls. Their experience with overhauls revealed two important features:—

(*a*) They were more economical in labour and time than were a series of minor inspections under similar operating conditions.

(*b*) Jet-engined aircraft showed no marked reduction in cost as expected from "lack of vibration."

The consistency of the flight results, although obtained in the rather special field of experimental flying, strongly suggested that no real progress in reliability or servicing ability had been achieved in recent years. He agreed that current operational types of jet engines were now only half the nuisance of piston engines, but it was barely a year ago when they were as much trouble. The reason for the improvement was that they had now embodied all the development modifications to the engines and their accessories.

The author had mentioned a "maintenance cell" in the drawing office. He had been told that the Royal Navy insisted on this feature with the design of their ships' machinery. He agreed entirely with the necessity for either a "maintenance cell" in the drawing office, or a "design cell" on the airfield. His experience was that aircraft reliability and ease of maintenance were largely "hereditary." By hereditary he referred to that virtue in aircraft design put into it at the start by a design team who had been producing particular types of aircraft for a long time and who had been assisted by the maintenance engineers concerned with their aircraft. The defects which occurred just before take-off were usually simple ones and thus were never officially reported; nevertheless, they seriously delayed times of take-off. By the designer's close contact with the operators and maintenance engineers, this hereditary trait seemed to develop more strongly as the firm's experience grew.

The Design Information Bulletins issued by the Society of British Aircraft Constructors illustrated design defects which had caused so much trouble in the past. No doubt senior designers were well aware of the errors, but it was obvious that often their juniors were not. Much benefit would be derived if these Bulletins were increased in scope and well circulated in the drawing offices.

Another old-fashioned principle that the author had not mentioned was that production shops once had the habit of advising drawing office staff of mistakes. Nowadays, once a drawing left the designer an article was produced exactly as drawn, including any errors that a drawing might contain. The production engineer was also responsible for many troubles which developed on aircraft. Outstanding examples were failures of rivets in tension due to sheets being pulled into shape instead of being pre-formed; sharp corners and burrs being left on components; welding "stiffness;" file marks; and unnecessary damage being caused to anti-corrosive coverings. Another serious trouble he often caused, through insufficient or inaccurate jigging in production, was difficulty in fitting replacement structural parts.

If aircraft were tested very early under real service conditions, subsequent modification action would be reduced, but it was not the complete answer because designers should have servicing advice at the conception of a design; often criticism of a prototype could not be made in time for improvements to be effected in production aircraft.

Maintenance engineers had spent the past few years in criticising the designer to such

an extent that he now wished to turn from scientific "aids" to "push-pull" controls. They had here the two extremes which also applied to the relative positions of the designer and the maintenance engineer in this problem of operating aircraft; each blamed the other for all the troubles. He thought there were other culprits. Were too many aids and instruments provided for the air crew? Was the traffic side of operational companies urged enough to make fuller use of fewer aircraft? Since the whole aircraft was a compromise, a far better approach would be for the designer, the scientist, the production engineer, the pilot and the maintenance engineer to get together and pursue a middle course on the inception of a new aircraft.

N. J. Hancock (Ministry of Supply, *Assoc. Fellow*) *contributed*: Surely the suggested "goal" of 100 hours between servicings should be 1,000 hours? Would not the lecturer agree that in these days they should be aiming for 1,000 hours and that any component which could not easily clear 100 hours should be redesigned or dropped immediately?

Quoting the old proverb, "No engine fit for civil use until obsolete" sounded like "passing the buck" to the engine designer—asking for proved reliability with futurist performance. Surely the development of engine and airframe should go on side-by-side? (Had anyone suggested that the Comet's engines were obsolete?)

The lecturer had made an unfair comparison between piston and turbine engines. Piston aero-engines embodied 49 years of development with attendant complexity, whereas turbine aero-engines, although only complicated by nine years of development, were already "blessed" with numerous problems, such as "creep stress," "lighting-up," "anti-icing" and many others. When the turbine engine "arrived" they were told that it was "just a pair of coupled wheels that kept going as long as 'any old' fuel lasted." It was less than nine years since the first turbine flew and already they had such new and undeveloped items as, torch ignitors, fuel accumulators, high-flow range, high-pressure fuel pumps, maximum speed governors, minimum burner pressure units and barostats or B.P.C.s. Those were just some of the accessories and each was so vital that it had to have its own private fuel filter and those were susceptible to blockage by "waxing" at altitude unless special fuel were used. Would the lecturer not agree that when the turbine engine had been "complicated" by 50 years of development it might possibly look worse than the piston engine of to-day?

V. A. Higgs (British Thomson-Houston Co. Ltd., *Assoc. Fellow*) *contributed*: Few aircraft manufacturers realised the vast developments that had occurred in aircraft electrical equipment. During the war it was realised that electrical power could provide a convenient light-weight and reliable method of distributing power throughout an aircraft. In consequence the electrical industry was called upon to develop a large variety of equipment for military aircraft to specifications which, apart from stating the performance required, also demanded the equipment to be as light in weight as possible consistent with absolute reliability during a life of 100 hours or less. To-day they were being asked for electrical equipment which would operate without attention for 1,000 hours both for military and civil aircraft. He thought this was an unreasonable demand and if achieved, as it probably would be at the expense of weight, was not really required. He would recommend a life of 250 hours for military and 500 hours for civil aircraft as far more practical.

Accessories were broadly divided into two types:—

1. Those developed with the hope that they would find general application in all or many aircraft and
2. Those developed for a particular application in a particular aircraft.

Since type 2 took longer to obtain and cost considerably more, the Aircraft Industry often used an accessory designed for general use and applied it to a special application. The micro-switch quoted by Mr. Bishop was a good example. His firm had recently developed a miniature switch for general application and considerable thought had been put into its development. It was not intended that this switch, weighing less than one-third of an ounce, should be operated in an exposed position by an undercarriage weighing several hundreds of pounds. He was certain that if Mr. Bishop and he were to get together they could develop a special version of that switch which would give absolutely reliable indication of an undercarriage position for a fraction of the weight of the mechanical arrangement.

Mr. Bishop rather missed the point when he referred to duplicated circuits and so forth. In the electrical industry they did not expect their circuits or indicator lamps to fail, but they did say that if the Aircraft Industry were concerned about the possible effects of failure they could easily duplicate the wiring. With most mechanical methods duplication was nearly impossible. Duplicated wiring and accessories usually resulted from the gentleman, referred to by Mr. Bishop, who said " what happens if. . . ."

Electronic valves always received a rough passage from users and yet the modern valve would give several thousands of hours service in aircraft applications, provided that it was applied correctly, loaded within the limits specified by the valve manufacturer, and pre-aged before use in aircraft. It was unfortunate that certain valve defects could not be found by ordinary routine testing and did not show up except in the first 50 hours' life. Arrangements were now being made to pre-age all valves for civil aircraft by running them on the bench for 50 hours before application to aircraft. He would recommend that the Ministry of Supply should also do this for military aircraft and introduce a range of pre-aged valves similar to the present CV range. Such a step would be most helpful to the designers of electronic equipment.

He fully agreed with Mr. Bishop in seeking to avoid complication. Many applications of electrical power were made for the very purpose of avoiding other complicated methods, but complicated electrical circuits must be avoided. Time and time again he had seen a comparatively simple circuit spoilt by the addition of relays to " do this " and relays to " avoid that " and other relays to protect the first ones, and so forth. Those electrical complications invariably arose from the Aircraft Industry or airline operator, coupled sometimes with over-enthusiasm from the electrical designer.

He believed that most of the defects occurring in electrical apparatus were due to lack of experience in the Aircraft Industry in applying that comparatively new tool. The electrical industry had a vast experience of the behaviour of electrical equipment on the ground and only a limited experience of the behaviour in aircraft. In order to get the best out of that " new tool " a much closer co-operation must be established between the aircraft firms and those electrical firms trying to develop aircraft equipment. Most aircraft firms had now found it necessary to establish an " electrical section;" it was usually under-staffed and its advice was often ignored. His experience was that the electrical engineer in an aircraft firm was usually the last person allowed to claim any space in a new aircraft design and the first person who was made to move or alter his equipment to suit the changes of design made by the aircraft designer. It was absolutely essential that the " electrics " of a new aircraft be considered and planned at the outset and not as an after-thought, as was so often the case.

If Mr. Bishop wished to receive a guaranteed life for his accessories he would first have to guarantee that his specified requirements were not exceeded and would have to specify his requirements far more exactly than had been the custom of the Aircraft Industry in the past.

S. M. Parker (Automotive Products Co. Ltd., *Assoc. Fellow*) *contributed*: Mr. Bishop had rightly stressed the importance of ensuring that bought-out equipment was fully developed. The soundness of this suggestion could not be disputed, but the difficulty lay in deciding how and when the necessary work should be done. In recent years great importance had been attached to the testing of complete systems and additional equipment for that purpose was now commonly ordered. He doubted, however, whether that gave the best results since there was a natural, but unfortunate, tendency to await the completion of the last parts of the system before testing the remainder, and since the need for last minute alterations was accepted as unavoidable in some instances, it could easily result in other parts of the system that were available remaining untested for a matter of months, which represented a loss of time that could never be regained. He thought that it would be a much sounder principle to permit accessory manufacturers to test units as they became available, particularly those units which were basically new. By so doing he believed that at least 90 per cent. of the snags would be eliminated and he believed that the remaining 10 per cent., attributable to the system as a whole rather than to the units individually, contained on the whole lesser problems which could still be dealt with in the time that would be left before the aeroplane had to fly.

The aircraft constructor, on whom the final responsibility lay, would achieve better results

if he asked for an endurance test certificate with each unit and concentrated less on completing a complete test installation in the early stages of development.

F. H. Robertson (Chief Project Engineer, Saunders-Roe Ltd., *Assoc. Fellow*) *contributed*: It was unfortunate that draughtsmen, aerodynamicists and stressmen could not be given injections for "anti-complexity" and "anti-weight" in the same way as anti-tetanus was injected.

Unfortunately, the rapid growth of the Aircraft Industry and the exigencies of war had caused an intake of half-trained technicians who were not, and never would be, engineers. Until those had been worked out of the system or sufficiently confined so as to nullify their bad influence, he must disagree with Mr. Bishop and plead for a "maintenance man" with a flaming torch to roar through the office daily and stamp on gadgets, fripperies, anomalies, abortions and all the other things of the devil which the boffin mind loved to produce. Mr. Bishop had forgotten that de Havillands had got such a man—his name was Bishop!

Design for maintenance, like design for economy or design for performance, sprang from the Project Office. Bad detail design could spoil a good project, but all the brilliant designers in the world could not make a good aeroplane from an ill-conceived project.

G. P. Watson (Blackburn and General Aircraft Ltd., *Associate*) *contributed*: Modification action to drawings to remedy servicing troubles, or to improve maintenance facilities, might not come to the knowledge of the man responsible for the original drawing. This was because work done on one section in the drawing office frequently changed hands by the time the development and teething trouble stage was reached. Neither the junior nor the senior draughtsman primarily responsible for the affected drawing therefore might ever hear of the trouble they had caused and one of the surest ways of learning, which was to know the mistake made, was lost.

Another important point with regard to the drawing office was the effect on the maintenance aspect of good co-ordination of the several teams engaged on the design of any one aircraft. The controls, electrical, equipment, and structural teams must be held together so that, for example, access to items were treated collectively wherever possible. A constant watch on each individual draughtsman's general activities by the design co-ordinator was the only sure method by which trespassing and fouling of one section with another and consequent difficulties in maintenance could be avoided. He was sure the cause of some maintenance troubles was incomplete design co-ordination.

When the design of the aircraft main component break-down points was considered, it would be found in many cases that the detail attention paid to the main structural connection at each point surpassed the attention paid to the details of controls and system breaks at the same point. This applied except where the requirements of power plant changes had concentrated attention on the provision of quick release couplings and good grouping of controls, with easy access, at fireproof bulkheads. To ensure good maintenance design of the complete aircraft it was important to provide similar "all-round" easy and accessible breaks at other component joints.

Coupled with this consideration was the condition in which a component was provided for replacement. He did not mean whether it was damaged but what was in it, or hung on it, such as provision for fairing fillets, hinged flaps, and parts of fuel, oil, hydraulic and electrical systems. The designer must consider carefully every spare before deciding the exact constitution of each item to avoid unnecessary dismantling or assembly *in situ* of associated items when fitting the spare. In addition, the designer must ensure that mating parts were sensibly and conveniently "broken down." While the operator who bought the spares should naturally watch those points, the ultimate responsibility for ensuring a practical assembly was the design team's.

MR. BISHOP'S REPLY

G. R. Edwards: He too considered that electrics were getting better, but he felt there was still a lot of room for improvement. It was a fact that, during the test flying of the Comet, more trouble was experienced because of the unserviceability of one V.H.F. radio set than with any other part of the aeroplane; and nobody seemed to know why. As an example of the type of thing he was criticising, he had had experience recently of a generator where no precautions were taken to prevent washers, and so on, from loose terminals falling into it; if a man who was making the connections happened to drop a

washer into it, there was nothing to prevent that washer falling into the gap of only 0.002 in. between the armatures.

The standard of design which was more or less instinctive in people designing aeroplanes did not appear to be achieved by those who designed small electric units; everything was very fiddling, and he felt that they were very much influenced by the idea that they were designing for static conditions on the ground, and that their products would not be subjected to vibration. It seemed that they had not yet acquired the idea that their products would be vibrated during flight and bounced about when machines were landing, and it seemed that a much higher standard of detail design was needed. He hoped the improvement Mr. Edwards had referred to would continue.

N. E. Rowe: The turbine engine would make a great difference in respect of vibration and he agreed that vibration due to gunfire on a fighter might be very serious; he had been watching the new 13 mm. gun fire, and it might well shake an aeroplane to an extent which would cause quite a lot of damage.

He had not heard of any trouble whatever in the Goblin and Ghost engines on the score of dust; certainly there had been no such trouble at Hatfield.

He felt sure that they could do a great deal towards the evolution of tests in conditions somewhere near those applying in operation, although they might not be able to simulate operating conditions completely. His Company had been testing, for example, cabin windows for the Comet. They had had one set on the roof for well over a year, exposed to all sorts of weather and with the correct cabin pressure applied to the window for eight hours each day and had made other tests, such as heating one side of the window and keeping the other side cold, over long periods. There had been tests of power-operated controls, which had been subjected to something like 100,000 reversals. Such tests, although not completely representative of operating conditions, invariably showed up troubles which would have developed after the aeroplane was in service.

Air Marshal Sir Victor Goddard: He was glad to hear from Sir Victor that there would be less regulations; he hoped the idea had been passed on to the Ministry of Supply!

Obviously the decision to dispense with duplication must depend on how vital was the particular service concerned. He agreed with Mr. Camm's remark concerning the duplication of the generator on a fighter; it seemed better to concentrate effort on one generator which would really work than to have two, both of which might go wrong.

S. Scott Hall: He gathered that Mr. Scott Hall had admitted that when the regulation on the tapping of blowers was issued, those concerned knew very little about the matter; that was just the point he had tried to make in the paper.

He did not think the suggestion that there should be Engineer Officers in the drawing office would work. It was surprising that 95 per cent. of maintenance people, when confronted with a problem concerning something of which they had not direct experience—a particular type of aeroplane, for example—could give very little help. When a variant was being made, as the de Havilland Company had just made in the Dove and the Heron, they could get lots of suggestions, because most of the bits were very similar. But when starting on a completely new aeroplane he had found that usually they did not get any help from maintenance people; it was rarely that such men were able to offer good constructive criticism when it was required.

C. G. A. Woodford: It might be true that firms got the electrics that they deserved. He doubted if the complete answer was to employ a consultant. They had tried this consultant idea for other specialised parts of the aeroplane and in general it had been a failure. The tendency now was for the larger firms to employ their own specialists. He was convinced that that was the right policy.

He would remind Mr. Woodford that speaking tubes were still provided on ships as a means of communication between the bridge and the engine room for use when the electrics failed!

Air Vice-Marshal Weedon: It would be a great help if those responsible for the reporting of defects would ensure that they were reported to the Industry in reasonable time. The trouble at present was that the Industry did not hear about them until months after they had arisen.

In the paper he had suggested that in peacetime a fighter should last for 500 hours, not 50 hours; and he believed it was true that there was only one Vampire in the R.A.F. which had done 500 hours' flying.

W. G. Bushell: The point that a great deal of maintenance trouble was due to corrosion and ageing of organic materials was very true. He was convinced that if they were going to achieve an aircraft which would remain serviceable for six months without continual dismantling for inspection, a great deal more attention must be paid to protection against corrosion and to finding materials which did not age and deteriorate due to heat, sunlight, oil, and so on. This was perhaps one of the biggest problems they had to face.

He was sure that it was not true of any large aircraft firm to say that the production shops did not advise the Drawing Office of mistakes on drawings—a very close liaison existed between the Drawing Office and the production shops during the design stage and throughout production.

V. A. Higgs: He did not agree that 500 hours' overhaul life of electrical components was sufficient in commercial operation; 500 hours was approximately two months' flying on an airline. They might have to accept a slight weight penalty in order to achieve a minimum of 2,000 hours' life.

He entirely agreed that a satisfactory micro switch could be developed; but so far it had not been.

It was not necessary to duplicate mechanical controls, because experience had shown that they did not fail. Experience with electrical units and controls as they had existed up to now showed that they did fail and so had to be duplicated. The whole point was that electrical units had got to be developed and made really reliable so that aircraft designers could have the same confidence in them that they had in mechanical controls and so avoid all the frightful duplication to cater for failures, which he was afraid at the moment were all too prevalent.

Mr. Higgs was undoubtedly right when he said that a closer liaison must be established between the electrical firms and the aircraft manufacturer. He would suggest, however, that there was a need for electrical firms to have on their staff someone who really understood the conditions in the aircraft under which their equipment would have to work. He was thinking of vibration, changes in temperature and humidity, and the need to make components easily removable, and above all the need to develop a reliable unit which would work satisfactorily under the conditions which occurred in the aircraft.

S. M. Parker: He entirely agreed that functioning and endurance testing of components of a system should be got on with as soon as the unit was available, without waiting for the complete system. There was never any substitute for time.

THE BERLIN AIR LIFT

by

Air Commodore J. W. F. MERER, C.B.

The 798th Lecture to be read before the Royal Aeronautical Society was given on 13th April 1950 at the Institution of Civil Engineers, Great George Street, S.W.1. Sir John S. Buchanan, C.B.E., F.R.Ae.S., President of the Society, introduced the Lecturer, Air Commodore J. W. F. Merer, C.B., R.A.F., who was Officer Commanding No. 46 Group, Transport Command from 1947 until the conclusion of the Berlin Air Lift in 1949, when he was appointed Director of Navigation and Control, Air Ministry.

INTRODUCING the paper Air Commodore Merer pointed out that the Americans, the French and the British were concerned in a close partnership in the Air Lift, but the Americans carried by far the larger portion of the load delivered into Berlin. The spirit of comradeship and endeavour which that joint task engendered was one of the heartening experiences of the operation and beyond all praise.

THE SITUATION

With the stoppage of rail traffic between Western Germany and Berlin by the Russians "for technical reasons" on 24th June 1948, all surface communications were finally severed. The British, American and French authorities were then faced with the necessity to transport by air the complete requirements of the German population of the Western Sectors, together with the Allied forces of Occupation and the Military Government staffs in the city, the whole totalling some two and a quarter million persons. These requirements represented an inflow of the order of 12,000 short tons a day prior to the severance of surface communications. By rigorous economies and adjustments these were scaled down by the Allied authorities within the city to about 4,500 short tons a day, which was an estimate of the minimum tonnage on which the city could subsist. The daily air lift of this tonnage was the task initially presented to the Royal Air Force and the United States Air Force, although the target was raised progressively as the months went by.

THE QUADRAPARTITE AGREEMENT

The problem of supplying Berlin by air was complicated by the limitations imposed by the Quadrapartite Agreement of November 1945, between Great Britain, U.S.A., France and Russia. Although this international agreement critically reduced the air space available for the air lift operations, both the British and American operating procedures were carefully designed to respect these restrictions.

Under the agreement all air traffic between Berlin and the Western Zones of Germany is confined within three corridors, twenty miles wide and extending from ground level to 10,000 feet, leading respectively to Hamburg and Hannover in the British Zone, and to Frankfurt in the U.S. Zone. The lengths of the corridors between the boundary of the Western Sectors of Berlin and their points of entry to the Western Zones are:—

Hamburg	...	...	95 miles
Hannover	...	...	117 miles
Frankfurt	...	...	216 miles

The two northern corridors traverse comparatively flat country, whereas the greater length of the Frankfurt corridor is over broken hilly country up to 3,000 ft. high.

All three corridors terminate in the Berlin Control Zone, a circular area of twenty miles radius centred in the heart of the city. Aircraft have freedom of passage within this area except within a two mile radius of Russian airfields, of which there are seven

in the small area in and around the city. Needless to say, no radio or radar aids to navigation were available to the air lift within Russian occupied territory.

EVOLUTION OF THE OPERATION

Although the Russians had imposed a series of progressively more rigorous restrictions on the movement of road, rail and canal traffic into Berlin during April and May of 1948, it was not fully apparent until a few weeks before the start of the air lift at the end of June that the stoppage was likely to become absolute. Little opportunity, therefore, was given to the British, American and French authorities for the deliberate preparation of plans for the air lift. Moreover, once the operation was mounted, there was little indication of its probable duration. This short preliminary notice and subsequent uncertainty are reflected in the evolution of the operation.

The Berlin Air Lift can be divided into four well-marked phases. The first, from June to September 1948 was one of rapid improvisation, in which the British and American efforts developed side by side in a loose co-ordination. The second, from October 1948 to February 1949 was marked by the creation, in the middle of October of the British/American "Combined Air Lift Task Force," by which the British and American operations were completely integrated. During this period the organisation of the British and American components of the Combined Force was consolidated and improved and common operating procedures were introduced. The third phase, beginning in March, 1949, saw the inception of long-term plans to sustain the air lift indefinitely on an agreed scale of effort calculated to provide a reasonably generous standard of life within Berlin and to maintain the industrial economy of the city.

The formal reopening of surface communications on 12th May 1949, was followed in July by the beginning of the final phase, the planned run-down of the air lift. The start of the run-down was delayed until the flow of supplies by road, rail and canal had developed to its former level, and a stock pile had been accumulated within the city as an insurance against a future stoppage; but it was completed by October 1949.

The first load of supplies on Operation "Plainfare," or "Carter Paterson" as the British share of the air lift was originally known, was delivered to Berlin by a R.A.F. Dakota on 28th June 1948. A small detachment of Dakotas of Transport Command had been positioned at Wunstorf a few days previously. These were joined by further Dakotas and Yorks of Transport Command which operated into Gatow, the terminal airfield in the British Sector of Berlin. From the beginning this transport force operated at maximum intensity throughout the 24 hours under the direction of the Commander-in-Chief, British Air Forces of Occupation, who was responsible for the conduct of the air lift within his Command.

Meanwhile, on 26th June, the U.S.A.F. had started the delivery of supplies into Tempelhof, the airfield in the American Sector of Berlin, using mainly C.47s based at Rhein-Main and Weisbaden. By October these C.47s had been replaced by C.54s. They labelled their share of the air lift "Operation Vittles."

On 5th July, the R.A.F. transport force was augmented by Sunderlands of Coastal Command which operated from a temporary base at Finkenwerde on the River Elbe, west of Hamburg, on to the Havel Lake, adjoining Gatow. They were joined early in August by two Hythe flying boats operated by a civil charter company. The flying boats continued to operate until 16th December when they were finally withdrawn because of the anticipated freezing of the Havel Lake and the risks of icing-up on take-off from fresh water. They were not subsequently reintroduced into the air lift because by the spring of 1949 the traffic flow down the corridors was approaching saturation point and the difficulties of fitting them into the pattern outweighed their usefulness. Throughout their operations they were handicapped by the lack of adequate ground aids for navigation and landing approach, and in consequence, their flying had to be restricted to daylight hours and visual flight conditions, but they provided a valuable contribution at a time when every ton was vital. Their introduction on the air lift was also a proof of our determination to use every means in our power to sustain the life of Berlin.

In point of fact the first civil charter company to be employed on the air lift began to operate from Buckeburg into Gatow on 27th July, carrying petrol in Lancastrians specially fitted with internal tanks. On 8th August they moved to Wunstorf where they joined a number of other civil charter aircraft

which had arrived there a few days previously.

By the middle of July the concentration of R.A.F. Dakotas and Yorks at Wunstorf had built up to over 90 and far exceeded the capacity of that station to operate the aircraft efficiently and to accommodate the personnel. At the end of the month the R.A.F. Dakotas were therefore moved to Fassberg where they were joined a few days later by nine civil Dakotas chartered for the air lift. The arrival at Fassberg on 21st August of three squadrons of U.S.A.F. C.54s necessitated a further move of the R.A.F. and civil Dakotas to Lubeck.

About the end of August there were indications that the Russians might be prepared to discuss the political situation in Berlin, the inference being that the restoration of the surface communications might result. The indications proved false and it now became evident that the air lift must not only be maintained at its existing capacity, but expanded considerably during the winter months ahead.

By this date the transport force operating from the British Zone comprised about 90 R.A.F., 30 British civil and 60 U.S.A.F. aircraft and was located at four bases, Wunstorf, Gassberg, Lubeck and Finkenwerde. The control of their operations, and in particular the co-ordination of the traffic within the corridors, and in the focal Berlin area, could no longer be handled effectively by the operations staff at Headquarters, B.A.F.O., who had been called on at short notice to undertake the planning and conduct of the air lift in addition to their normal tasks. Moreover, the air and ground crews, were beginning to feel the strain of a most intensive and prolonged routine which had evolved on the supposition that the operation would be of short duration. Among the factors which contributed to this strain were the very long hours which the individual, of necessity, had been called on to work and fly daily since the beginning of the operation, and the frequently over-crowded domestic accommodation. It must be remembered that the airfields used had been selected more or less in haste because of their immediate availability and their geographical proximity to the air corridors. None were suitable for intensive and continuous air transport operations without extensive additions and alterations, both to the technical installations and to the domestic housing. In general terms the operation had expanded to a stage where a specialised control and a wider decentralisation of the organisation were needed.

On 22nd September an advanced operational headquarters was detached to Germany from Headquarters 46 Group, which I was at that time commanding in Transport Command, to assume the control, under the orders of the Commander-in-Chief, B.A.F.O. of all the British aircraft engaged on the air lift. My "Advanced Headquarters, No. 46 Group" as it was called, consisted of a skeleton operations staff, including signals, navigation, air movements and air traffic control specialists and technical staff, the whole totalling twenty-one officers and airmen.

My responsibilities were two-fold:—

To the Commander-in-Chief, B.A.F.O. for the control and utilisation of the British air transport operations, and their co-ordination with those of the U.S.A.F. units based in the British Zone.

To the Commanders-in-Chief, Transport and Coastal Commands for the correct employment and utilisation of the aircraft and crews, air and ground, supplied by them.

The administration of the R.A.F. airfields in Germany from which the aircraft operated was retained by Headquarters, B.A.F.O., but at the beginning of December "Advanced Headquarters No. 46 Group" was expanded to a full transport group establishment, with certain additions to cover the special requirements of the air lift, and assumed complete control of its air lift bases. It is of interest that the U.S.A.F. organisation for the control of operations within the American Zone developed on almost identical lines.

The arrival of further R.A.F. and civil Dakotas at Lubeck during September had resulted in the over-crowding of that station, and on 5th October the 10 civil Dakotas were transferred to Fuhlsbuttel, the civil airport of Hamburg controlled by the Civil Aviation Division, Control Commission, Germany. The transfer of the civil Dakotas to Fuhlsbuttel created a situation unusual even for Operation "Plainfare." Hitherto all the civil charter companies' aircraft had been located at R.A.F. stations where their operations had been co-ordinated with those of the R.A.F. squadrons by the Station Commander, their crews accommodated and certain services provided by the R.A.F.

Although their operations continued as before to be directed and controlled by Headquarters 46 Group, the services previously provided by the R.A.F. were now provided by the Control Commission, Germany (C.C.G.). The executive authority at the airport was the Airport Manager. The airport civil operations staff was supplemented by R.A.F. operations officers for briefing and operations control duties.

In the middle of September, the R.A.F. Dakota force at Lubeck was joined by a Royal Australian Air Force squadron of 12 complete crews. A South African Air Force squadron of 10 crews arrived in October, followed in November by three complete crews of the Royal New Zealand Air Force. These Commonwealth crews flew the R.A.F. Dakotas and operated continuously up to the end of the air lift as an integral part of the Dakota force.

By the end of September it had become clear that to ensure maximum efficiency and safety, a much closer co-ordination was required in the control of the combined traffic flowing into Berlin from both the British and the American Zones. The main factors to be considered in the design of a common traffic pattern were:—

The difference in navigation technique between the R.A.F. and U.S.A.F., to which I shall refer later.

The differences in speed and performance between the nine types of British and American aircraft using the northern and central corridors. By early October R.A.F. Yorks and civil Lancastrians, Tudors, Haltons and Vikings were located at Wunstorf; R.A.F. Dakotas at Lubeck; civil Dakotas and Wayfarers at Fuhlsbuttel; R.A.F. Sunderlands and civil Hythes at Finkenwerde; and U.S.A.F. C.54s at Fassberg.

And finally, the physical volume of traffic, and the need to equalise the flow into Gatow and Tempelhof. The British/American aircraft operating into Berlin now totalled about 250. The average number of landings in 24 hours at each airfield was:—

Gatow	...	380
Tempelhof	...	220

The proposal then under consideration for the transfer of a further 30 or 40 C.54s from the Frankfurt area to the British Zone, in order to reduce their time of flight into and out of Berlin, would further aggravate the difficulties.

Associated with these operational factors was the major principle that the supply of Berlin should be treated as a common Anglo-American problem, and that the control of the R.A.F./U.S.A.F. air lift activities should be centralised, if possible.

Discussions between Headquarters, B.A.F.O. and Headquarters, U.S.A.F.E. resulted in the establishment on 15th October of the "Combined Air Lift Task Force" with General Tunner in command and myself as his deputy commander. Provision was made for an integrated U.S.A.F./R.A.F. staff for the combined Headquarters. The Combined Headquarters was located at Weisbaden, but it was agreed that I should remain with my Group Headquarters at Buckeburg. Very close contact was maintained subsequently by weekly visits by me to the Combined Headquarters, and by frequent staff visits.

In the joint directive issued by the A.O.C.-in-C., B.A.F.O., and the Commanding General, U.S.A.F.E., the mission and function of the Combined Air Lift Task Force were defined as follows:—

"Its primary mission is to deliver to Berlin in a safe and efficient manner the maximum tonnage possible consistent with the combined resources of equipment and personnel made available.

"Its major function shall be generally operational in nature rather than administrative. The Commanding General is given command over all U.S. units and operational control of R.A.F. units to which aircraft are assigned, and which are directly engaged in the air lift effort."

It is significant that the mission of the Combined Air Lift Task Force had now become virtually an all-out effort to supply "the maximum tonnage possible" in the difficult winter period which lay ahead.

On 1st November the first squadron of Hastings arrived at Schleswigland, which had been opened a short time previously as a "Plainfare" station, and began to operate into Berlin on 11th November. They were joined by a number of civil Haltons from Wunstorf fitted for the carriage of liquid fuels.

Tegel, the third airfield in Berlin, was opened for air lift traffic on 1st December, three months after the ground was first broken. The project, which had been

planned at the beginning of September in anticipation of the traffic saturation of Gatow and Tempelhof by the expansion of the air lift, was remarkable not only for the speed of its completion but also as a practical symbol of the solidarity of the Western Allies. The site was located in the French Sector of Berlin, the construction was undertaken by American engineers, the flying operations were subsequently controlled by the U.S.A.F., and it was commanded and administered by the French. British and American aircraft operated into it.

Celle was opened on 15th December as a base for a group of four squadrons of U.S.A.F. C.54s. The decision to develop this second base for the U.S.A.F. in the British Zone had been taken late in September by Headquarters, B.A.F.O. and Headquarters, U.S.A.F.E. for the following reasons:—

The lack of sites in the U.S. Zone at the entrance to the Frankfurt corridor suitable for rapid development as bases for the additional C.54s which were planned for the air lift.

The far higher utilisation of aircraft which would result from the shorter distance to be flown to and from Berlin. Consideration had been given at the time to the transfer of the major portion of the C.54 force to the British Zone for this reason, but a study of the weather differential through the year between the British and American Zones showed the desirability of maintaining half the force in each Zone. Later experience proved the wisdom of the decision, at least in the winter months, since on a number of occasions weather stopped operations completely in the one Zone, while they were able to continue uninterrupted in the other.

A further factor was the logistic difficulties which would have resulted from the transfer.

The preparation of the airfield was a remarkable piece of work by the Airfield Construction Branch of the Air Ministry Works Department. In two and a half months a 2,000 yd. concrete runway and concrete taxi tracks were laid, together with a loading and servicing area in pierced steel planking to accommodate 40 C.54s. Domestic accommodation was converted or constructed for more than 2,000 U.S. officers and men.

The command and administrative systems at Fassberg and Celle were similar. Both were R.A.F. stations commanded by R.A.F. officers, although in March 1949, the command of Fassberg was given to a U.S.A.F. officer. The U.S.A.F. retained the control of their own operations and technical servicing, the latter with the assistance of the R.A.F. station workshops. Discipline, in the case of the U.S.A.F. personnel, was administered by the senior U.S. officer.

With the coming of the New Year, there was still no sign of a break in the deadlock over the surface communications with Berlin and the preparation of long-term plans for the future was undertaken. A smooth and effective operational system and procedure had been evolved in the past months; the working hours and conditions of the individual had been carefully regulated to minimise fatigue and physical strain. The organisation had successfully stood the test of the bad weather of November, December and January. The operational and technical installations and the domestic accommodation on the airfields must now be improved to a standard which would permit the aircraft and their crews, both air and ground, to maintain the highest possible level of efficiency over an indefinite period.

A personnel factor of major importance was the period which the individual could be expected to continue on the air lift without loss of efficiency in the prevailing conditions. All the R.A.F. air crew were serving in Germany on attachment from Transport Command. Many had been employed continuously since the beginning of the operation, certainly with regular periods of rest in England but for a few days only at a time. The majority of the technical personnel, in the same way, was attached from Transport and other home Commands, although a scheme had been in operation since December for the rotation of the individual back to his parent station in England after a minimum period of three months in Germany.

For the purpose of the plan the R.A.F. daily tonnage target was reassessed at 1,000 tons. This would involve the maintenance of a potential lift of 1,400 tons a day to compensate bad weather periods. The size of the R.A.F. transport force to be maintained in Germany was planned to achieve this target. By a staggered rotation of the individual squadrons for a period of three months in Germany, followed by two months

in England, it was estimated that the air lift could be kept going at the required intensity. At the same time the crews could be given their annual leave and undergo essential training, and would be available for certain standing strategic commitments which, of necessity, had been scaled down during the air lift. In the implementation of the plan, provision would be made for the re-arming of the Dakota squadrons with Hastings, so increasing the total load potential of the force.

The long-term plan so far as it affected personnel could only be implemented gradually, but on 1st May all R.A.F. technical and administrative personnel attached from home Commands were replaced or transferred to the B.A.F.O. establishment. The squadron rotation plan was brought into operation on 1st July. The aircraft which belonged to Transport Command returned periodically to the United Kingdom as before for base servicing; the air crew would continue to be attached to B.A.F.O. during their tour in Germany.

A start was made in February with an extensive programme of construction on airfields, the intention being to extend the facilities on the six existing base airfields in the British Zone to enable them to operate up to 60 four-engined aircraft each, and to prepare a seventh to the same standard. The construction of a third runway at Gatow was also started.

On 15th March, Headquarters, No. 46 Group was moved from Buckeburg to Luneburg where better accommodation and signals communications were available and which was more centrally located in relation to the air lift stations in the British Zone.

Following the discussions between Russia and the Western Powers, surface communications between Berlin and the Western Zones were reopened at midnight on 12th May, and the end of the air lift operation was in sight. However, for the reasons I have already stated, the decision was taken to continue the air lift at its existing intensity. It is of interest that the daily average British lift of 1,920 tons throughout June was its highest in any month during Operation "Plainfare," and that on a number of days during the month the tonnage exceeded 2,000.

In July, the British effort was scaled down to a slightly lower intensity and on 1st August the planned run-down of the air lift began. By mid-August all the civil charter aircraft had been withdrawn; on 26th August the last squadron of Yorks left, and on 23rd September the Dakotas which had opened the air lift 14 months previously, flew their last sorties into Berlin. A small force of Hastings remained to keep alive the technique of the air lift against future eventualities.

CIVIL AIR LIFT DIVISION

The civil aircraft employed on the air lift were chartered by the Foreign Office, who appointed the British European Airways Corporation as their charter agents. On 4th August 1948 the B.E.A.C. Regional Manager, Germany, was given the responsibility on behalf of the Corporation for the supervision of the charter companies' activities in Germany in addition to his duties as Commercial Manager. This date may be regarded as the formal inception of the Civil Division of the Air Lift although, as I have described earlier, a number of civil aircraft were already operating before that date. Liaison officers were also provided by the Corporation on the R.A.F. stations in Germany to provide a channel through which the R.A.F. could pass their instructions.

Throughout the operation the R.A.F. exercised the operational control of the aircraft and provided domestic accommodation, hangars and workshop facilities on the station, technical assistance and certain services, such as M.T. and petrol, oil and lubricants. Fuhlsbuttel was a special case as I have pointed out. The flying and ground personnel were integrated into the life of the R.A.F. stations, sharing the amenities and, I should add, the earlier discomforts of the improvisation phase.

At the beginning of December, an operations staff was provided by B.E.A.C. in the Operations Control on each of the three airfields to provide a closer co-ordination of their operations with those of the R.A.F. under the Station Commander; and an administrative officer to look after their administrative problems. In February, the B.E.A.C. Regional Manager was appointed "Manager, Civil Air Lift" and relieved of his other duties to enable him to devote his whole attention to the operation. On 1st April the Corporation created an autonomous "Civil Air Lift Division" under him which joined my Headquarters at Luneberg, and the integration of the R.A.F. and civil operations was then complete.

The expansion and composition of the civil fleet are an interesting study. In August 1948, the average strength was 17 aircraft consisting of eight Dakotas, three Haltons, two Hythes, three Lancastrians and one Liberator. Of these 82 per cent. were dry freight carriers. By May 1949 the average daily strength had expanded to 47 capable of maintaining a daily lift of over 750 tons. On 22nd May, their record day, 1,010 tons were lifted. During that period, the composition of the fleet had undergone a radical change. The twin-engined light load carriers had been replaced by four-engined aircraft; and by May 76 per cent. of the aircraft were engaged on the carriage of liquid fuels. At one time or another during the operation, no fewer than 23 charter companies, as well as B.O.A.C. and B.S.S.A., took part and 10 different types of aircraft were used, including the Dakota, Halton/Halifax, Hythe, Lancaster/Lancastrian, Liberator, Lincoln, Tudor, Viking, Wayfarer/Freighter and York. By the end of the air lift the civil fleet had delivered 146,980 tons to Berlin in 21,921 sorties, a tonnage which, I believe, is almost double the weight of mail and cargo carried by all British civil aircraft on scheduled services in the 23 years from 1924 to 1947.

The liquid fuels, consisting of petrol, kerosene and diesel oil, deserve special mention as the entire civil and military requirements of Berlin were carried almost exclusively in the British civil charter aircraft. The first three civil aircraft to join the air lift were Lancastrians carrying petrol. By May 1949 the tanker fleet had expanded to an average strength of 36 aircraft, consisting of 7 Tudors, 13 Haltons, 14 Lancastrians and 2 Liberators, based at Wunstorf, Schleswigland and Fuhlsbuttel. The daily average tonnage of fuels lifted for that month was 578 tons, against the target of 550 tons. The system employed at Wunstorf and Schleswigland was to pump the fuel into the aircraft from bulk underground storage tanks. They were de-fuelled at Gatow and Tegel by gravity, also into underground storage tanks. An underground fuel installation with pressure delivery was under construction at Fuhlsbuttel as part of the long-term plan when the air lift ended.

Apart from the diversity of aircraft types, the companies themselves differed considerably in material resources, personnel strength, operating standards and technical efficiency. In the early days some of the aircraft lacked de-icing equipment and the requisite radar navigation aids. The supply of spare parts for some of the aircraft types was a source of anxiety right up to the end of the air lift. With all these factors it was difficult indeed in those days to assess the operational potential of the fleet, but by the spring of 1949 most of the uncertainties had been resolved. Thereafter an intensive, if occasionally somewhat irregular, effort could be counted on. The experience of the air lift showed that the civil charter companies can provide a highly effective contribution in strategic air transport operations alongside the R.A.F. if certain principles are observed; and emphasised their importance as a potential strategic reserve.

PROCUREMENT AND HANDLING OF SUPPLIES

The basis for planning by all agencies involved in the procurement and handling of the commodities required by Berlin was an advanced forecast of the capability of the transport force issued monthly by Headquarters, Combined Air Lift Task Force (C.A.L.T.F.). This was presented as an estimate of the daily tonnage which could be lifted.

The allocation of the tonnage and the priority in delivery of the commodities to meet the specific requirements of German subsistence and industry and of the occupation forces, was made by the Berlin Air Staff Committee composed of representatives of the American, British and French Military Governments within the city. No subsequent departure either from the allocation or from the priority was permitted without clearance by them.

The firm allocations were transmitted in turn to the Berlin Air Lift Co-ordinating Committee (BEALCOM), the procurement agency, located in Frankfurt and composed of representatives of the British and American Control Commissions, the two Army movement and suppy organisations, and the C.A.L.T.F. traffic staff. Thus, in the case of the British, it was ultimately the responsibility of the Control Commission Germany (C.C.G.) to arrange the procurement and delivery of the supplies to the air lift bases in conformity with the agreed programme and priorities.

The supplies arriving at the airfields in the British Zone, including Fassberg and Celle,

and at Gatow, were handled by a British Army formation known as the Army/Air Transport Organisation (A.A.T.O) which is a standard organisation for air transport operations, although its establishment may vary according to the nature and scope of a particular operation. The Headquarters, A.A.T.O., commanded by a brigadier, was located with my own Headquarters and in effect we worked as one integrated formation to ensure the closest possible liaison, which was so obviously essential. The Commander, A.A.T.O. not only instructed his units on the airfields of the quantities and priorities of commodities to be loaded daily, but also advised the C.C.G. on stocks to be maintained on airfields, and co-operated with the bi-zonal authorities in the preparation of the delivery programme. He advised me on the allocation of the commodities to particular airfields and on the specialised installations for handling and loading. All the motor transport and German labour required for loading and unloading was controlled by the A.A.T.O.

The A.A.T.O. unit on each base airfield was the "Rear Airfield Supply Organisation" (R.A.S.O.) which received and stored the commodities and loaded them into the aircraft under the supervision of the R.A.F. Air Movements Section. The latter were responsible for the documentation and the correct disposition and lashing of loads in the aircraft.

The unit at Gatow was the "Forward Airfield Supply Organisation" (F.A.S.O.), which unloaded the aircraft and handed over to the representative of Military Government Berlin the commodities for the German economy, and to the British military authorities the supplies for the British occupation forces. Backloads from Berlin either of German civilians, mail or freight, were handled by the R.A.F. Air Movements Section. I should add that the volume of backloaded traffic was quite formidable and that by 1st October 1949, just prior to the termination of the air lift, the R.A.F. had flown out of Berlin a total of 98,000 German passengers, 23,800 tons of mail and 11,800 tons of freight, the latter mainly the manufactured products of the German factories in the city. British passengers are not included in these figures. The relief of two of the British battalions in the city, together with their families, was undertaken as part of the normal routine of "Plainfare."

The supplies carried into Berlin for the German population can be broadly divided into food, coal, liquid fuel and economic freight, which included the thousand and one items not included in the other categories. As I have already pointed out, the daily minimum supply requirements for the civil population and the forces of occupation was originally estimated in June 1948 at 4,500 tons. This estimate was revised in October to 5,620 tons, broken down approximately as follows:—

Food	26 per cent.
Coal	55 „ „
Economic Freight ...	5 „ „
British, U.S. and French Forces	14 „ „

As the air lift tonnage capacity progressively increased, it became possible to improve the daily ration of the city's inhabitants and to raise the living conditions to a higher standard. Liquid fuel was substituted as far as was practicable for coal, since it was easier to handle and provided more effective heating. Nevertheless, it is of interest that of the total weight of supplies delivered by the combined air lift up to the end of July 1949, about 65 per cent. was coal. The tonnage of food carried remained constant at about 25 per cent.

The variety in the nature, weight and bulk of the commodities to be carried complicated the work of selection, loading and lashing in the aircraft. Awkward items, such as steel girders and electric generating plant for the Berlin West power station, bulldozers and M.T. vehicles, had to be lifted, in addition to the normal domestic commodities, which themselves presented special problems. Thus aircraft floors had to be sealed against coal dust and flour. To avoid corrosive effect, salt, of which 38 tons were required daily in Berlin, was carried in the flying boats, which were anodised, and after these were withdrawn, in Halton freighters, fitted with external panniers. Packaging was drastically reduced or removed to save weight; where possible food and vegetables were dehydrated. Finally, to facilitate handling, the smaller items were broken down into units of about 200 lb., and the coal was bagged in units of 100 lb. Light bulky commodities were balanced with heavy items to utilise fully the weight capacity of each aircraft.

The diversity of types of British aircraft added further to the problem. Factors

which had to be allowed for were the size of the aircraft door and its location, the height of the cabin floor above ground level, floor strength and angle when the aircraft was in the loading attitude. All the British aircraft had side doors, with the exception of the Bristol Freighter and Wayfarer. The experience gained with the latter emphasised most powerfully the advantage of end-loading for intensive freight-carrying operations, not only in the physical process of loading, but also in the total size of the hardstanding area required by the aircraft. With side doors additional space was required to enable the vehicles delivering the loads to manœuvre up to the aircraft, and the risk of damage to the structure by careless driving, particularly at night, was increased. Moreover, since the hardstanding area had to be surfaced with bitumen or pierced steel planking, the preparation of the airfields called for additional works services. For ease of loading the aircraft doors themselves should be as large as possible to take bulky freight or vehicles, and the aircraft floor should be horizontal in the loading attitude.

Trial and error showed that for normal loads the most speedy and effective system was to use 10-ton lorries, since that was the capacity of the largest aircraft, and to transfer the loads direct from the lorry to the aircraft by hand. This system had also the great advantage of flexibility in dealing with the numerous types of aircraft with their differing features. Fork lifts, and in exceptional cases loading ramps, were used for the bulky awkward items. Each lorry had a standard team of men and the whole process, including the backing up to the aircraft, was reduced to a meticulous drill. The U.S.A.F. were in the happier position of operating one type of aircraft, the C.54, although they also used a number of Fairchild C.82s from their zone. Moreover, their squadrons at Fassberg and Celle carried mainly standard loads of coal, a factor which gave them a quicker turn round and hence a higher utilisation rate.

OPERATIONAL CONTROL ORGANISATION

A limiting factor in the delivery of the maximum tonnage into each of the terminal airfields in Berlin was the planned rate at which they could accept, unload and turn round the aircraft. It was essential, therefore, that the aircraft should arrive on the boundary of the Berlin Control Zone uniformly at the planned rate. Apart from the collision risks in instrument weather and at night, if the aircraft failed to maintain their uniform intervals, large adjustments in cruising speed on route from base were both undesirable and impracticable. In the final analysis, therefore, the uniform rate of arrival on the boundary of the Berlin Control Zone depended on effective control of the time of take-off from its base of each individual aircraft.

At the peak of the air lift, the aircraft from all six of the widely separated airfields in the British Zone had to be phased into a steady stream at uniform intervals within the northern corridor. The problem of control of the stream consisted of two parts:—

The co-ordination of the flow from all the airfields.

The control at each airfield of the despatch of individual aircraft.

The traffic pattern and the block times of despatch from each airfield were planned by Headquarters, Combined Air Lift Task Force. The co-ordination of the flow of aircraft based in the British Zone to conform with the current plan was exercised from the Operations Control Room at my Group Headquarters, which was in direct telephone communication with the Operations Control Room of each station, with Headquarters, C.A.L.T.F. and with the Area Air Traffic Control Centre.

The elements involved in the despatch of individual aircraft from each airfield in accordance with the traffic plan were:—

Nomination of the air crew.

Technical servicing and preparation of the aircraft.

Loading.

Despatch in conformity with the preplanned schedule.

Each of these four "elements" was directed at the airfield by a subsidiary control through which the Station Operations Control exercised its function of co-ordination. The layout of the control organisation was standardised on all the R.A.F. stations. The technical and load controls were always located alongside one another, since the servicing and loading of individual aircraft had to proceed concurrently, if delays in despatch were to be avoided.

In practice, therefore, I maintained a continuous supervision of the operations

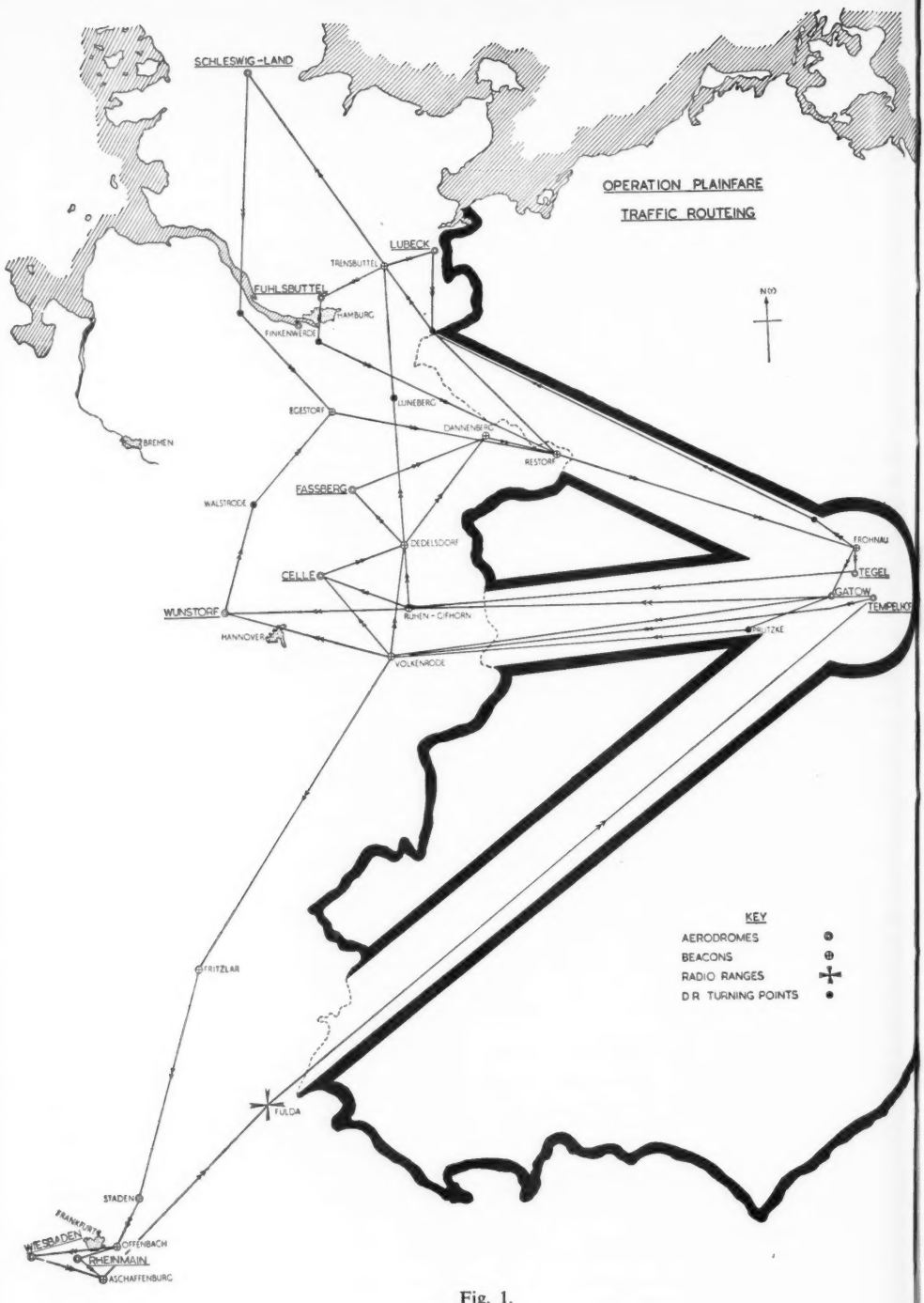


Fig. 1.
Traffic pattern.

from each station, including Gatow, through my Group Control; each Station Commander exercised his direction through his Station Control and its four subsidiary controls.

The task of "air crew control" was to provide an air crew for each sortie, at the same time ensuring that the individual had regular rest and sleep and a balanced share of day and night flying.

It was found by experience that the maximum sustained intensity of flying which could be expected of a crew without loss of efficiency, was about 70 hours a month and two consecutive sorties in a 24-hour period; the "working day" should be limited as nearly as possible to 8 hours. The "cycle" of duty for each individual had to allow not only for adequate rest and sleep between periods of flying, but also periodic leave, and squadron rotation between the United Kingdom and B.A.F.O. when the rotation scheme was introduced. The employment of crews therefore followed a certain rhythm not readily susceptible to adjustment.

The rhythm could be upset locally by the diversion or delays of crews away from base because of weather or aircraft unserviceability, by delayed return from the U.K. from leave, by postings, or an unexpected incidence of sickness among members of the same air crew trade. The random "crewing up" of individuals did not provide the ready-made solution since the individuals of a scratch crew might have to be brought into step.

The "technical control" was responsible for progressing the turn round of aircraft, including refuelling, rectification and scheduled servicing. Detailed state boards were maintained continuously for each aircraft on the station, from which the technical control could estimate within minutes the time at which it would be ready to take off after turn round from a previous flight, or after rectification. The time an aircraft was forecast as serviceable for flight was passed to air crew and load controls to enable them to co-ordinate their own detail.

The "load control" was an integrated R.A.F. Air Movements/Army R.A.S.O. Section, responsible for making up aircraft loads and calling them forward for loading into aircraft while the latter were being refuelled. By close co-operation between the load and technical controls it was possible to match loads to aircraft, so that awkward freight which would have taken some time to load was placed in aircraft which were undergoing minor rectification. In this way serviceable aircraft were not delayed on the ground unnecessarily.

In addition to its normal functions of control, air traffic control was responsible for ensuring that aircraft were despatched exactly at the planned time. For this purpose the take-off times for each aircraft were passed to the Air Traffic Controller by the Station Operations Control.

TRAFFIC PATTERN

The flight between the base airfields in the British Zone and the terminal airfields in Berlin consisted of three phases:—

Climb and let-down pattern in the base area.

Traverse of the corridors.

Let-down and climb pattern in the Berlin Control Zone.

In the later stages of the air lift, the inbound traffic from the British Zone was fed into Tegel and Gatow down the northern corridor, while that from the U.S. Zone went into Tempelhof. All outbound traffic used the centre corridor with the exception of the Fuhlsbuttel and Schleswigland aircraft, which returned up the northern corridor below the incoming streams.

Traffic from the six British airfields converged on the northern corridor, where it was phased into two continuous streams superimposed on each other, the 500 ft. height levels between 1,500 and 2,500 ft. being assigned to the Tegel traffic, and those between 3,500 and 5,500 ft. to the Gatow traffic. One height level was alloted to the aircraft of each station, with the exception of the C.54s from Fassberg and Celle. The 3,000 ft. level was kept clear as the emergency altitude.

Aircraft climbed out from their base to operating height at an allotted air speed and were routed to the entrance of the corridor to avoid as far as possible the climbing and let-down patterns of the other bases. A wide detour was obviously impracticable and, where traffic streams crossed, a minimum vertical separation of 1,000 ft. was established at the cross-over point. The turning points and the corridor entrance were marked by radar beacons for the British aircraft and by M/F beacons for the American. In view of the navigational limitations of the U.S.A.F. C.54s, each

alternate aircraft was stepped up 500 ft. as a safety measure. Thus each U.S. block occupied two height levels. As a further safety measure, blocks of aircraft of different types were separated horizontally by a 6-minute interval. The same principle was employed in routeing the traffic back to the bases from the western end of the centre corridor.

At the Berlin end, the two inbound streams down the northern corridor diverged at Frohnau, the Gatow traffic over-flying Tegel. Outbound, the Tempelhof traffic flew at 7,500 and 8,500 ft. to clear the traffic returning to the British Zone at the lower altitudes.

The density of the traffic in the Berlin airfields can be visualised from the total number of flights into the three airfields in 24 hours, which ranged from an average of 868 in April to 886 in July 1949. Each flight involved a landing and take-off. On 16th April, when an all-out effort was made to test the traffic procedure, 2,796 movements were made into and out of Berlin by the C.A.L.T.F., or one every 30.9 seconds throughout the 24 hours. The tonnage lifted that day was 12,940.

SYSTEM OF DESPATCH OF AIRCRAFT

At the beginning of the air lift, when the aircraft in the British Zone used the central corridor only, they were despatched in a continuous flow at uniform time intervals and with an appropriate height separation between different types. Each aircraft was allotted a time to pass over a check point 20 miles from Gatow and the navigator computed his flight plan backwards from that time to determine his take-off time. Later, when the number of despatching bases had increased and one-way traffic down the northern corridor and out by the central was introduced, the check point was established at Frohnau at the Berlin end of the northern corridor in the French Sector and "marked" by a radar beacon.

The arrival at Fassberg of the U.S.A.F. C.54s with their different navigation technique necessitated the modification of the system of continuous despatch. The R.A.F. aircraft carried a navigator and were equipped to use Gee, radar and M/F beacons. Therefore they could navigate the flight plan accurately, pin-pointing their positions in all weather conditions and at night, since they had a continuous check on course to steer and distance to run from the radar beacons marking the turning points in the traffic pattern. By this means they were enabled to maintain a correct spacing within the aircraft stream at all times by reference to the ground. The C.54s on the other hand carried no navigator and relied

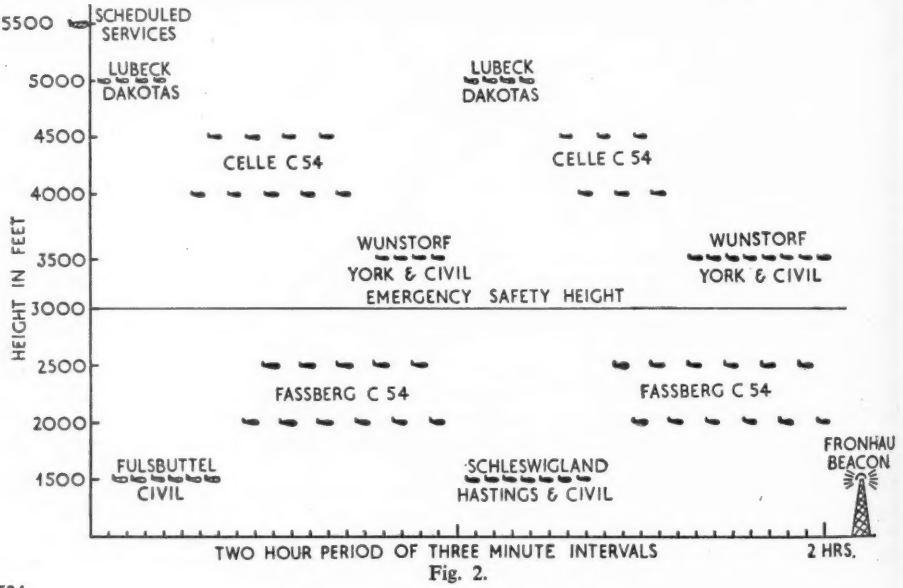


Fig. 2.

on radio ranges and M/F beacons, and visual/aural ranges. They were unable, therefore, to pin-point their position between beacons, except in visual flight conditions and they depended on accurate course keeping and maintenance of the correct air speed to preserve their spacing in the aircraft stream. Any marked change in the wind velocity from that used in the flight plan might obviously affect the spacing of each aircraft relative to its neighbours and that of the C.54 block relative to the rest of the stream.

To enable the British and American aircraft to be phased into the traffic stream and to maintain a continuous flow, a "time block" despatch system was devised by which each base was allocated blocks of time over Frohnau, the radar beacon there being supplemented by an M/F beacon for U.S.A.F. use. As the C.54 was the heaviest load carrier and, with its standard load, was able to complete a sortie cycle in approximately four hours, including unloading in Berlin, and refuelling and reloading at base, the duration of the block was fixed at four hours to ensure their maximum utilisation. Each block was repeated six times a day. On the other hand, the sortie cycle of the British aircraft with their non-standard loads, their differing performance and their longer flight times, frequently exceeded four hours. The recurring peak load thrown on the servicing and loading organisation rendered it impossible to turn round some of the aircraft in time for the next block despatch, with a consequent loss in their utilisation.

The substitution of a two-hour block for the four-hour block went some way towards ironing out the peak loads on the British organisation and it improved utilisation by ensuring that an aircraft which was ready to fly too late for one block despatch, did not have to wait upwards of four hours for the next. To secure a further improvement, an hourly despatch system was subsequently adopted. Each airfield in succession flew off a wave of aircraft at an interval of three minutes between aircraft, the total despatch occupying a period of an hour.

The lesson to be derived was that if circumstances prevent the adoption of "continuous despatch," which is the most efficient system, and the time block system is employed as an alternative, the frequency of the block cycle and the number of aircraft in each block require very careful consideration.

RATE OF DESPATCH

At the beginning of the air lift, aircraft were spaced at six-minute intervals. This was later reduced to three minutes as the number of aircraft increased and the efficiency of the operation improved. Eventually, when Gatow had two runways in use, one for landing and one for despatch, a despatch rate of one aircraft every two minutes was achieved in visual flight conditions. In instrument conditions it was found that an experienced G.C.A. team could handle traffic at a maximum sustained rate of one every five minutes, and over short periods up to about an hour, a rate of one in three minutes was achieved. On one occasion 241 landings were made in 24 hours at Gatow under G.C.A. control, that is one every six minutes. The experience emphasised the necessity for two parallel runways, one for take-off and one for landing at the terminal airfields. A third runway is, in fact, required to allow for repair and maintenance of one of the runways at a time.

DISTRESS AND RECALL PROCEDURE

An aircraft in difficulties which could not maintain its height and speed was an immediate danger to other aircraft in the corridors. The procedure in these circumstances was to turn out of the aircraft stream and return to base at the emergency altitude of 3,000 ft., which was kept clear of all normal traffic for this purpose.

British aircraft maintained a W/T watch in flight with the Area Air Traffic Control Centre and could be diverted or recalled as required. To ensure that all aircraft acted on a general recall signal together, they were given a specific time at which to alter course for base or the diversion airfield. U.S.A.F. aircraft did not carry signallers and could not be diverted when outside R/T range.

AIR TRAFFIC CONTROL

The control of traffic in the Berlin area presented a complex problem, since all the aircraft converged on three airfields located within a circle of six miles' radius. Any form of holding or stacking was dangerous, and unacceptable because of the delays imposed. A traffic system, therefore, was

developed in which the aircraft checked over the beacons at the Berlin end of the northern and southern corridors and let down on a timed approach pattern. The air speed, rate of descent, and the height over certain points in the pattern were laid down in the standard flight procedures. Where necessary, because of the proximity of two traffic streams, turning points in the pattern were marked by radio and radar beacons, as for example the point at which Gatow traffic turned from base leg to finals for landing in an east-west direction. G.C.A. was employed for approach and let-down in instrument flight conditions, but B.A.B.S. was also installed at both Gatow and Tegel for use by the British aircraft. Aircraft unable to land at their first attempt were not allowed to re-enter the approach pattern but were required to overfly the airfield and return to base, except in emergency. The problem for the outbound traffic from Berlin was obviously more straightforward, but here again aircraft had to conform to a rigid traffic pattern.

In the control tower the control was exercised by a team of three watch-keeping officers, an approach controller, an airfield controller and a supervisor, the three officers exchanging duties every two hours to make up a six-hour watch. This system was general on all the R.A.F. airfields. It is of interest that a number of Royal Naval air traffic controllers were employed at Gatow.

The routine for Gatow traffic was that the aircraft called approach control 20 miles short of Frohnau beacon and was instructed to adjust its height to 3,500 ft. over the beacon. It was then given a runway touch-down time and checked through the various points in the pattern to the point where it was handed over to the airfield controller, or in instrument flight conditions, to the G.C.A. final controller for its final approach.

Early in 1949 an American Traffic Control Search Radar (C.P.S.5) was installed at Tempelhof and was jointly manned by R.A.F. and U.S.A.F. controllers in an organisation known as the "Berlin Approach Control Centre." The apparatus consisited of three pairs of P.P.I.s, each pair watching the traffic for one of the three airfields. An aircraft approaching Berlin by either the northern or southern corridors was picked up by the "airway controller" on the longer range P.P.I. at a distance up to 50 miles, identified by a procedure turn and given the necessary adjustments of course and air speed to arrive over Frohnau beacon at the correct time interval from its neighbours. At the beacon the aircraft was handed over to the "approach controller" on the short range P.P.I., who monitored it through the approach pattern to a point where it was in turn handed over to the "airfield controller" in the tower, or the G.C.A. final controller, depending on the weather conditions. Each controller had a complete picture of the traffic movements into the three airfields.

Although the traffic procedure was not materially altered by the use of the C.P.S.5, the additional safety factor allowed a minimum spacing interval to be used in instrument flight conditions. Moreover, traffic could be diverted with safety from one airfield to another. In the event of instrument failure the normal tower control procedure came into operation. Arrangements were in hand for the installation of a C.P.S.5 at the entrance to the northern and southern corridors when the air lift ended. I would like to add as a tribute to the traffic control organisation and the air crews, that in over a quarter of a million flights into Berlin in all weathers and at night, I know of no recorded case of a collision.

One of the major difficulties experienced in the control of traffic was the inadequate number of R/T frequencies in the aircraft. The Berlin approach procedure necessitated 12 separate frequencies. Some of the aircraft carried eight and the remainder four only. A compromise had to be adopted, therefore, in which a particular frequency might be used for two functions. The very heavy volume of traffic also called for strict R/T discipline and an abbreviated R/T procedure.

TARMAC CONTROL

Air traffic control at the terminal airfields in Berlin was continuously occupied in clearing aircraft for landing and take-off and issuing taxi-ing instructions to aircraft on the runways and perimeter tracks. This situation existed to a lesser degree at the base airfields, since the movement of aircraft on the airfield was not continuous. The control of the movement both of aircraft and motor transport in the loading areas could not be exercised, therefore, from the airfield control tower.

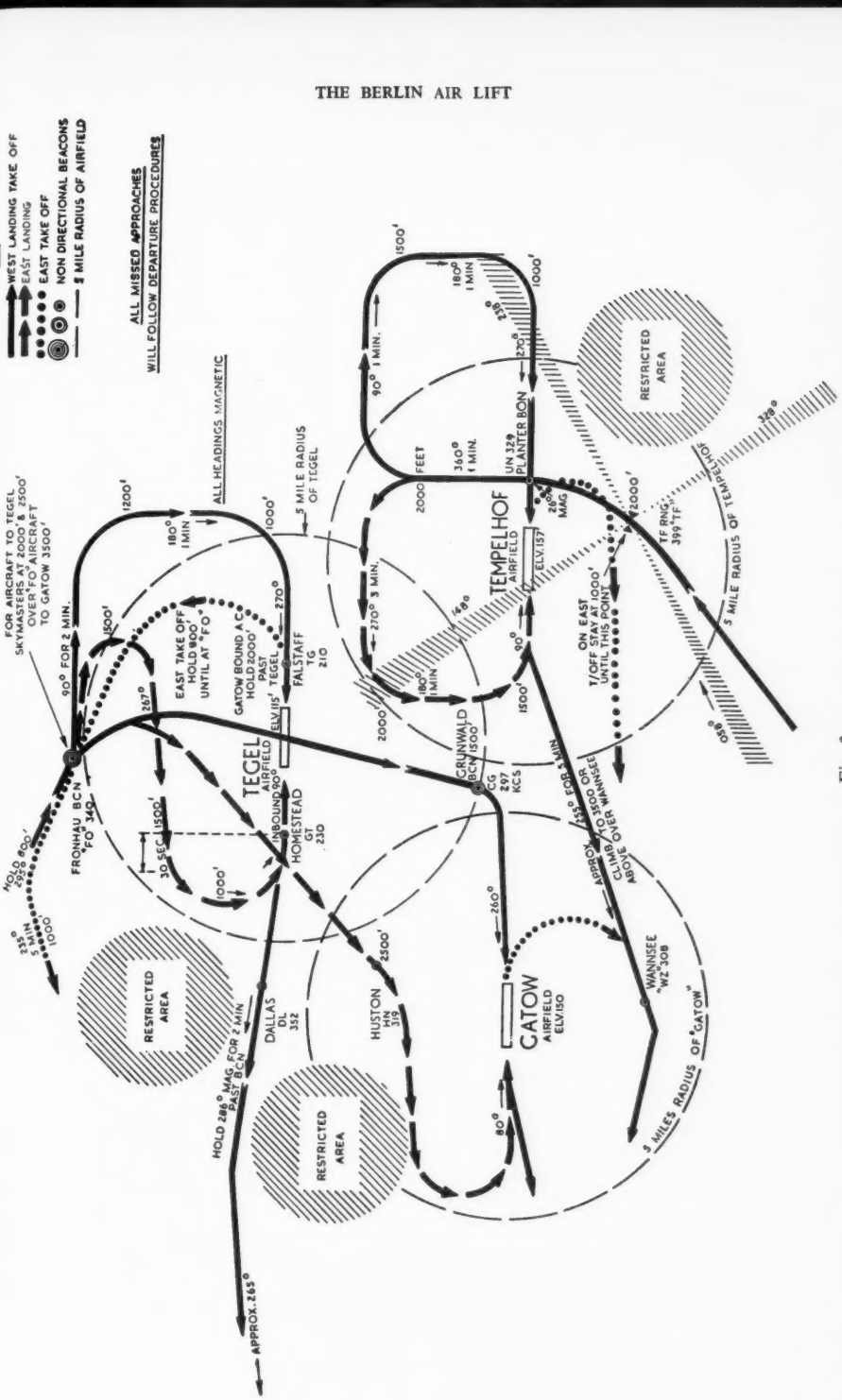


Fig. 3.
Air Traffic Control. Berlin area procedures.

Accordingly, at Gatow the responsibility for the marshalling of aircraft and the control of M.T. in the loading areas was delegated to "tarmac officers." Immediately an aircraft turned off the runway, it was given brief taxi-ing instructions by Airfield Control and was then marshalled into position on the apron by a team of marshallers under the supervision of the tarmac officer. The marshallers were stationed at vantage points in the marshalling area, and the aircraft was passed progressively from one marshaller to the next until it reached its standing. Conversely, aircraft leaving the apron received taxi clearance from Control and were marshalled off the apron by the marshalling team. At some of the base airfields, marshalling of aircraft was done by a "lead in" vehicle which met the aircraft at the entrance to the marshalling area and led it along the taxi-tracks to its allotted position on the apron, where a marshaller gave the pilot final movement signals.

AIRFIELD LIGHTING

The installation of centre line and horizon bar approach lighting was completed at Gatow and Wunstorf in October 1948. Subsequent experience showed that it was a great improvement on any previous visual approach system. It was found, however, that some form of control was required to adjust the light intensity to suit visibility conditions, as pilots experienced difficulty in adapting their vision rapidly at night from the brilliancy of the sodium approach lights to the relatively dim runway lighting. Effective rheostat control of the sodium lights was not possible and the lights were duplicated with 100 watt filament lamp bulkhead fittings. These lamps could be adjusted to "bright," "medium" or "dim." Thus four stages of brilliance were available, the sodium for bad visibility and the three stages of filament lamp adjustment in rather better conditions. In clear weather the cross-bars were switched off, leaving the centre line of lamps pointing to the threshold of the runway. So convincing was the result of the tests that the decision was taken to fit the lighting at all air lift stations in the British Zone.

To improve the runway illumination, American high intensity lighting was installed. Its adoption and the use of the aircraft landing lights in the final stages of the approach did much to minimise the difficulty previously experienced by pilots in their visual adaptation.

The standard taxi-track lighting was found to be insufficiently powerful to mark the edge lines, especially when seen against the background of powerful lights illuminating the hardstanding area, and on a misty or rainy night. I should add that it was important that aircraft should taxi at the highest speed, consistent with safety, to avoid congestion and to reduce turn-round time. The light shrouds were removed, therefore, and the lights were mounted on 12-inch posts. As an additional aid, white lines were painted down the centre of taxi-tracks and "leads-in" to the hardstandings.

As a general practice flood-lighting of the loading hardstanding was effected by mounting lights on 30 ft. poles around the perimeter and at appropriate points within it. The disadvantages lay in the great number of lights required for effective area illumination and the fact that each pole constituted a taxi-ing obstruction. As an experimental measure, two 60 ft. steel towers, each carrying a circular cluster of twelve Hollophane wide-beam 500 watt lamps, were erected in the hardstanding area at Celle. This method proved relatively effective and afforded the advantage that it reduced the risk of taxi-ing accidents. Tests with 1,000 watt lamps were about to begin when the air lift ended.

Among the problems of airfield lighting which were not satisfactorily solved on the air lift and which, I suggest, merit further study, are area lighting and the harmonisation of approach, runway, taxi-track and area lighting in intensive operations of this nature.

EFFECT OF WEATHER ON OPERATIONS

The weather during Operation "Plainfare" varied from normal, in that the very cold spell of about six weeks' duration which normally occurs in the late winter, failed to materialise, so that the winter fogs which began in early November persisted into early March and were particularly frequent at Schleswigland, Fuhlsbuttel and Gatow. The moist north-west winds normally confined to the first half of the summer, extended from early July to mid-August in 1948 and from mid-June until early August in 1949, frequently causing airfields to close down in the latter half of the nights.

Little interference with operations was experienced during the winter from snow and ice on the runways and the measures prepared for dealing with these problems were not seriously tested. The prolonged fog periods, on the other hand, interfered seriously with the operation, although flying was continued down to weather minima of 800 yards horizontal visibility and cloud ceiling 200 ft., with the help of radar and lighting approach aids. In the absence of an adequate landing aid, however, flying had to be discontinued when conditions fell below these limits.

Cross-winds also caused a loss of sorties for the British aircraft with their conventional tail-wheel landing gear. Experience showed that they could not land with a full load with an assurance of safety in cross-winds exceeding about 12/15 knots broadside across the runway. This limitation was severe as the runways at Gatow, Tegel, Fuhlsbuttel and Lubeck are sited in one direction only. On the other hand, the C.54s with their tricycle undercarriages had little difficulty in operating in winds up to 30 knots across the runway.

One of the important lessons which emerged from the air lift was the big advantage of the tricycle undercarriage over the tail-wheel type, not only for cross-wind operation but also in increased manœuvrability on the ground and for added directional control on take-off and landing.

Icing in flight caused little interference, except to certain of the Haltons which were not fitted with de-icing equipment, and it was necessary to re-route them below 3,000 ft. Since icing conditions could not be avoided by an alteration in course and height, it was sometimes necessary to use the de-icing equipment at the maximum rate throughout the flight and to replenish the fluid in Berlin before the return flight, because of the inadequate capacity of the fluid containers in the aircraft.

Thunderstorms were encountered on a large number of occasions and numerous instances were recorded of aircraft being struck by lightning, sometimes twice on one flight, but negligible damage to the aircraft structure or instruments resulted. A more serious problem was the extreme turbulence associated with the thunderstorms. As in icing conditions, cumulus cloud could not be avoided by an alteration of course and height, nor could speed be adjusted over any appreciable range. The only course open to the pilot was to continue with his flight plan or to adopt the safety procedure and return to base.

A close and continuous watch was maintained on the weather in the Group Operations Control by means of actual reports telephoned every hour from the bases and the Berlin airfield, and by an organised system of reports from aircraft captains. Moreover, a meteorological forecasting section was located alongside the control room to provide periodic forecasts and continuous consultation. By this means the controllers could maintain the traffic flow up to the safety limit with confidence in marginal weather conditions and resume it with minimum delay after interruption.

INFLUENCE OF AIRCRAFT PAY-LOADS ON ECONOMY OF OPERATION

One of the more striking object lessons of the air lift was the advantage in economy of operation of the heavy load carriers. The C.54 or the Hastings presented no greater problem than did the Dakota in operating along the corridors into Berlin or in loading and unloading. Yet the load delivered by the Dakotas was approximately one-third that of the others. This disproportion in the load carried is not reflected in the "overheads" in air crew and servicing personnel as the following figures for a task of delivering 4,500 tons a day to Berlin for 30 days show:—

	No. of trips	Crews	Aircraft	Maintenance personnel	Fuel used (gallons)
C.54	13,800	465	178	4,674	8,577,600
Dakota	39,706	1,765	899	10,588	14,294,000

These figures, which were supplied by the U.S.A.F. on experience gained in the Frankfurt corridor are based on the assumption that the payload of the Dakota and C.54 is respectively 3.4 and 9.7 tons per trip; and the maximum flying hours a crew are 90 a month.

At the peak period of the operation, the R.A.F. and civil charter companies were flying one-third of the total sorties daily, although the tonnage they lifted was only one-quarter of the combined total. The discrepancy was due almost entirely to the lighter load capacity of the British aircraft, particularly the Dakota, compared with the 10-ton load of the C.54. It emphasises

sharply the necessity for the employment on an operation of this nature of the heaviest possible load carriers consistent with operational factors, such as the strength of the runways.

CONCLUSION

Some months before the termination of the full-scale operations on 31st July 1949, the air lift had settled down to a steady routine which could have been continued indefinitely with the existing organisation and resources. Within certain predictable limits, the daily tonnage could have been increased by refinements in the organisation and by the additional resources which had been planned.

A significant improvement in the performance of the air lift followed the progressive standardisation of techniques and procedures in the combined British/American force. Conversely, the diversity in the types and equipment of the British aircraft, inevitable in the circumstances, intensified a number of the problems.

Except for November and December, when fog and gales stopped flying, the tonnage mounted steadily month by month until by May 1949 the daily average was over 8,000 tons. The aircraft actively engaged at that date totalled about 95 R.A.F., 45 civil and 200 U.S.A.F. By the end of July 2,231,600 tons of supplies had been delivered to Berlin by the Combined Air Lift Task Force, a high proportion of which had been carried by the Americans. This total represents an average of 5,579 tons a day throughout the operation. The British contribution was just over half a million tons, of which the R.A.F. had lifted about 70 per cent. and the civil companies 30 per cent.

Some of the factors which contributed to the success of the operation, and the lessons which emerged from our experiences, I have endeavoured to describe. To my regret, in the time available, I have not been able to make more than a passing reference to the splendid support from the ground staffs, technical and administrative, without which the fine skill and determination of the air crews might have been rendered ineffective.

The Berlin Air Lift was an integrated British-American effort in the fullest sense, involving as it did not only their fighting services but a number of civil departments and agencies. It demonstrated their will and ability to combine in a great strategic, and I should add humanitarian, undertaking in peace no less than in war. That it was successful is due in large measure to the enthusiasm, loyal co-operation and comradeship of all those who had a share in it.

DISCUSSION

Air Chief Marshal Sir Ralph Cochrane (*Associate Fellow*): He endorsed what Air Commodore Merer had said about the valuable contribution of the civil air operators. Even the smallest charter companies, anyone who could produce an aeroplane and the pilots to fly it, was contributing to the general air power of the country and that was clearly demonstrated in the Berlin Air Lift.

Having been involved recently in one of those circular systems which seemed to spring up around major airports, he was particularly interested to hear Air Commodore Merer say that they had refused to have anything to do with " stacking " and he heartily supported his view on that subject. He thought there were three main reasons why on the Air Lift they managed a very high rate of landing in all weather conditions without resort to that time-wasting practice.

First, the entire operation was under unified control and one man could plan the flying and see that the aeroplanes were spaced at whatever was the agreed interval.

Second, the crews had available, certainly the British crews had, an effective navigation system. He was delighted that Air Commodore Merer had mentioned the distance measuring equipment which they had had in the Air Force for a number of years and which provided the crews with the means of securing even spacing in the traffic stream.

The third reason was that all the pilots were under a common discipline and were engaged in a common task in which they took a corporate pride. The aircraft could therefore be relied upon to be where they were supposed to be and they were thus able to achieve a high rate of landing. It was to be hoped that the experience gained might be of value in the solution to the problem at civil airports.

Brigadier Dawson (War Office—Commander of Army Air Transport Organisation

during the Berlin Air Lift): Although they in the Army were not responsible for the procurement of the supplies to be taken to Berlin—that rested with the Control Commission for Germany—they were responsible for seeing that they were on the airfield in the right quantities at the right time. One of their most important duties was to ensure that no aircraft was ever kept waiting without a load. In the forms which were used there was a space headed "Time at which aircraft took off" and there was a blank space in which a cross could be put under the heading "Aircraft delayed through Army Loading"; he was glad to say that that space was never filled in throughout the operation, or possibly only once.

Standard packing had been one of their great worries. When they began they had to take the supplies in whatever packing was readily available. They had many different weights and sizes for the same commodity, and when they got de-hydrated potatoes—they had had to go all over the world for them—they had as many as fifteen different weights and packages. Towards the end of the operation nearly all the commodities were in standard packages. With coal they had no trouble because no one had ever thought of sending that by air before so they started from the beginning.

They had had to ensure that they got the quickest turn-round possible for the aircraft. They received hundreds of letters of advice, suggestions and so on, all well intended he was sure, for the best and quickest way of loading an aeroplane. They tried every one, but in the end came to the simple procedure of putting their loads on a ten-ton lorry and taking it to the aeroplane. That was the most effective way in the circumstances of the Air Lift. One day perhaps the aeroplane would come to rest at the exact spot where it was wanted, but until then the load had to be taken to the aircraft.

To those who had to design transport aircraft he would suggest that they started with the door and then built the aircraft round it. That would help very much, and in considering the aircraft as a whole perhaps they would stop worrying about such things as "centre of gravity" and ensure that the aircraft were impervious to the somewhat elephantine approaches of Army ten-ton lorries!

E. Whitfield (B.E.A., Head of the Civil Air Lift Division): Air Commodore Merer had covered almost everything that had been done on the civil side of the Air Lift, but he would like to draw attention to the Avro Tudors. The average utilisation of the civil aircraft on the operation was 1,800 hours a year. The Tudors produced an average of 2,000 hours a year and flew 9,524 hours, carrying over 30,000 tons into Berlin. They had done it very successfully without a major accident of any kind, and he felt that as these aircraft had been much maligned in the past their achievement on that very gruelling operation, for which they were not designed, should be known.

He would like to pay a tribute to the help and support that the civil operators had received from the Royal Air Force and the Army in general. They had made very many calls on them for assistance and not once had a call gone unanswered. In fact, the team work that ruled throughout the operation was the keynote of its success.

Miss A. M. Kennedy (*Companion*): Were all aircraft equipped to carry such large loads of liquid fuel? It must have been carried on a scale unheard of before the Berlin Air Lift.

Air Commodore Merer: All aircraft engaged in carrying liquid fuel were specially fitted for the purpose with internal tanks which would take up to the full load the aircraft could carry.

Geoffrey Dorman (*Associate*): When he was at Gatow in November 1949 he was told of a Globemaster which made two or three landings at Gatow and was then told not to come again. Was an aircraft of that load-carrying capacity really punishing the runway so badly that it could not have been used for any length of time?

Air Commodore Merer: Runway wear was one of their serious worries. Even with the concrete runways they found that the surface started to crack after a time as the result of the continuous pounding from the aircraft landing and taking off. That was why he had stressed that at Gatow three runways were required, one for landing, one for take-off and the third undergoing maintenance. At Tegel, which was built very rapidly and with the material available in Berlin, the construction was of brick rubble surfaced with bitumen and rolled hard. After a few months the surface of the down-wind end of the runway started to "wrinkle" badly and a number of minor accidents to the Haltons

on landing were due to this cause. A second runway was under construction, and it was rather a race against time since major repairs on the original could not be undertaken until the second was ready for use. The American construction engineers with their usual energy and hustle won the race and finished the second runway before the first showed signs of breaking up.

The point was that the constant hammering of the runways produced a fairly rapid deterioration. The Globemaster operated into Gatow for a few experimental flights, but it was doubtful whether the runways were strong enough for it to operate continuously.

It should be emphasised that runway strength was one of the big limiting factors in that type of operation.

F. L. Sawyer (Ministry of Civil Aviation): One of the possible ways of reducing delays around airports might involve the more extended use of ground radar. He was interested in the references to the use of C.P.S.5 at Tempelhof; could Air Commodore Merer give any actual figures which showed any increase in landing rate made possible by the use of that equipment, or was its effect that of providing greater safety at the same rate?

Air Commodore Merer: He had not the actual figures, but for R.A.F. aircraft which carried D.M.E. the landing rate was not greatly influenced by the introduction of the C.P.S.5. In their case the maximum landing rate was governed primarily by the number of runways available. Using one runway only at Gatow it was physically impossible to reduce the landing interval below three minutes, because the aircraft taking off also had to use the same runway. With two runways, the landing interval could be reduced to two minutes in visual flight conditions. The D.M.E. enabled the R.A.F. aircraft to maintain consistent intervals in flight and so achieve a consistent landing rate down to the physical limit stated. The Americans on the other hand, without D.M.E., had a much more difficult task in making allowance for changes in wind velocity, particularly in marginal or instrument flight conditions. In the worst case on the long flight up the Frankfurt corridor an aircraft had on odd occasions drifted outside the corridor due to strong, unpredicted cross-winds. To that extent they derived greater benefit from the C.P.S.5 than did the British.

The C.P.S.5 was undoubtedly of great value, however, in adjusting the intervals for all aircraft and smoothing out the flow. It also gave greater flexibility in the handling of the traffic, since aircraft could with confidence and safety be diverted from one airfield to another in the Berlin area in an emergency. Finally, it was a very positive insurance against collision through unforeseen circumstance.

J. A. C. Manson (Fairey Aviation Co. Ltd., *Fellow*): The Ministry of Supply had offered the help of the Aircraft Industry for the base servicing of the aircraft which were brought back at regular intervals for overhaul in the United Kingdom and very early in the operation it had been accepted by the R.A.F. Four firms were used in the servicing of Dakotas and three in the servicing of Yorks, and the mean turn-round time was between three and five days according to the stage of base inspection that was required.

To what extent had the necessity of bringing the aircraft back to the United Kingdom from Germany affected the operation and how much use was made of those returns in the relief of the crews engaged in the operation?

Also, what did the Americans do? Did they do their servicing in Germany?

Air Commodore Merer: It would have been most uneconomical to have transferred the large and complete base servicing organisation to Germany, more especially since the flight time between the United Kingdom and Germany was comparatively short. For that reason the decision was taken at the beginning of the operation to return the aircraft to their home stations in the United Kingdom for periodic inspections. Almost invariably the aircraft were fully loaded on their flights to and from the United Kingdom with air and ground crews, or with spares and equipment, and in that respect also the decision was justified.

It was obviously essential that an aircraft should not be withdrawn from the operation for an hour longer than was necessary for inspection, more especially in the critical period in November and December when the number of aircraft available was barely adequate to lift the tonnage required. The servicing undertaken by the civil contractors, to which Mr. Manson had referred, was both effective and prompt in turning round the aircraft. There were perhaps occasions when

week-ends and bank holidays interrupted the flow of the aircraft back to Germany at a time when every single one was badly needed, but in general the scheme had worked well and the civil contractors had made a valuable contribution.

The Americans flew their C.54s back to their base at Burtonwood in England for their 200-hour inspections. For their 1,000-hour inspections they were flown back to the civil contractors in the United States. All other maintenance was done in Germany. Here again there was a close similarity in the British and American organisations.

Wing Commander Gibson (Airborne Forces Experimental Establishment): Had any consideration been given to gliders?

Air Commodore Merer: The possibility of using gliders had been closely studied, but it had been proved conclusively that they would have been considerably less economical than powerful aircraft in the circumstances of the operation. Moreover, their employment was, he understood, contrary to the terms of the Quadrapartite Agreement, although he had not had the opportunity to study the Agreement in detail.

Sir Roy Dobson (A. V. Roe & Co. Ltd., *Fellow*) *contributed*: It would appear that Great Britain was lacking in air transport facilities to cope with any serious large-scale emergency which might arise, and to-day they were probably worse off in that direction than at the time of the Air Lift, on account of the severe treatment meted out to Transport Command, which even at the time was obviously inadequate to cope with the situation, hence the bringing in of every suitable civil aircraft which could be made available.

It seems to him that in view of what had been said in the lecture, and present-day circumstances, it was impossible to escape the conclusion that for a wartime operation the present constitution of Transport Command would prove entirely inadequate.

The Air Lift bore no real relationship to wartime operation because distances were so short and therefore only small fuel loads had to be carried, and the weight of freight could be increased and so every aircraft was flying at very nearly its maximum payload and minimum fuel. In addition, the payload was mainly such that it could be conveniently stowed, whereas in wartime awkward loads would have to be carried and that would add considerable difficulty and reduce the effective use of both the cubic capacity and weight-lifting qualities of the aircraft.

The lecture indicated the excellent way in which a host of practical obstacles were overcome, but it was obvious that Transport Command, as a unit of the R.A.F., needed considerable strengthening if it were to fulfil its proper function in time of war.

THE DRAG EFFECTS OF ROUGHNESS AT HIGH SUB-CRITICAL SPEEDS*

by

A. D. YOUNG, M.A., A.F.R.Ae.S.

SUMMARY

Measurements were made in the Royal Aircraft Establishment High Speed Tunnel of the drag of a wing with various grades of surface roughness in the form of camouflage paint. The measurements were made for a range of Reynolds number from about 4.5×10^6 to about 15×10^6 at a constant Mach number of 0.2, and for a range of Mach numbers from 0.2 to about 0.7 at a constant Reynolds number of 4.5×10^6 and to about 0.6 at a constant Reynolds number of 6.0×10^6. It was found that for the range of Mach numbers tested compressibility had no appreciable effect on the drag increase due to roughness (Figs. 2 and 3). Further, the drag effect of each roughness tested was such that an equivalent size of sand roughness K_e, of the type tested by Nikuradse, could be readily associated with it. For each finish tested a number of roughness records were taken by means of a roughness gauge developed by Dr. Tomlinson, of the National Physical Laboratory (Fig. 5).

An analysis of these records showed that the equivalent sand roughness height was about 1.6 times the arithmetic mean roughness height $\bar{K}$, and in general was much the same as the height of the largest roughnesses that could be said to occur with fair frequency. Estimates were then made of the effects of the various finishes tested on the drag of wings and bodies for ranges of wing chord or body lengths, forward speeds and heights (Fig. 6), and the results have been applied to assess the effects on the top speed performance of representative fighters and bombers. They indicate, for example, that a finish having an equivalent sand roughness of about 0.0004 in. should have no serious effect on the top speed of a small fighter capable of about 550 m.p.h. at 40,000 ft.

1 INTRODUCTION

The work described in this paper was done primarily to solve the specific problem of the effect of camouflage paint on profile drag, a problem which was of some importance during the 1939-45 War but which is now of less significance. Nevertheless, both the problem and the results obtained present several features of fundamental and permanent interest, and the main object of this paper is to draw attention to these features.

In 1933 Nikuradse[1] published the results of his classic experiments on the drag of sand roughened pipes. His results remain (up to 1946) the only experimental data on the effect of roughness on drag that are both systematic and comprehensive enough to permit of generalisation. The generalisation was made by Prandtl and Schlichting[2], who produced their well-known charts for the drag of sand roughened plates with fully turbulent boundary layers. Their results are reproduced in a more convenient form in Fig. 1, where the ratio of the drag increase due to roughness to the drag of the smooth plate ($\Delta D/D$) is plotted against the Reynolds number of the plate for various values of the ratio of the roughness height to the plate length (K_e/l)*.

*This paper was read at the International Congress of Applied Mechanics in Paris, 1946, and the author is indebted to the Ministry of Supply for permission to publish it. The diagrams and photographs are Crown Copyright.
Mr. Young is now Professor of Aerodynamics at the College of Aeronautics.

*This is substantially the same diagram as that of the Royal Aeronautical Society Data Sheet, Wings 02.04.08.

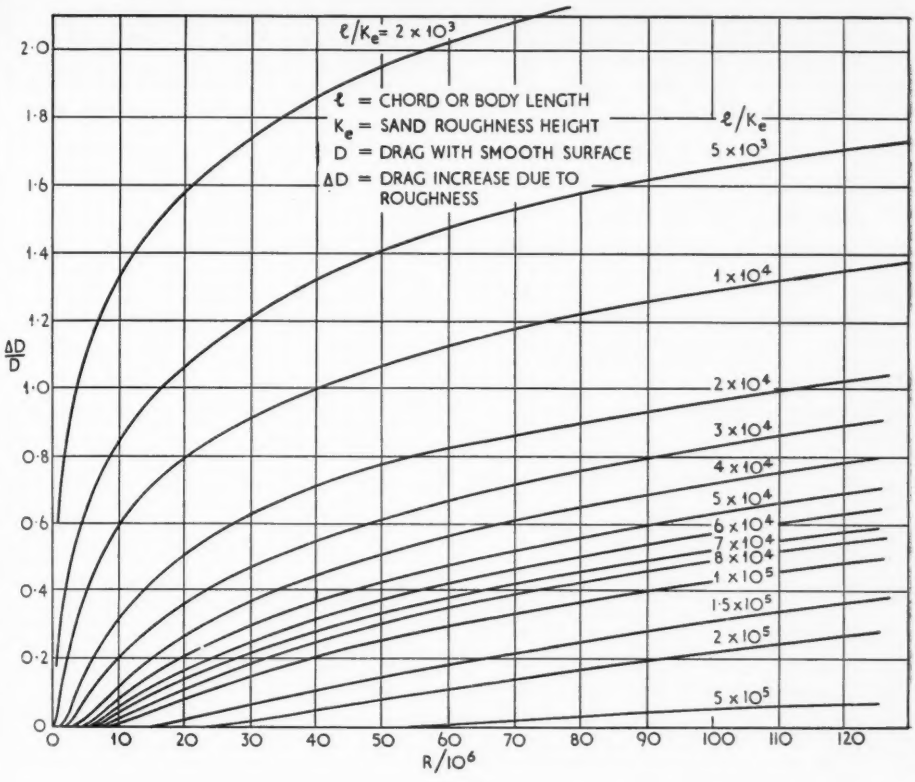


Fig. 1.

It is assumed that although these curves apply strictly to the frictional drag of roughened flat plates they will apply to the profile drag of similarly roughened wings and bodies, if for the plate length (l) we read wing chord or body length. This assumption is based on the following argument. The profile drag of a wing or body can be regarded as the sum of the skin friction drag and the form drag. The latter, however, is a function of the former, since it derives from the presence of the boundary layer and its effect on the pressure distribution. It is known that for a good streamlined shape the ratio of the form drag to skin friction drag is small and varies only slightly with the skin friction drag when the latter is altered by altering the transition point position[3, 4]. It seems reasonable for our purpose to assume that this ratio is constant for a given streamline shape and independent of all factors which may alter the skin friction drag, including surface roughness. It may also be assumed that the fractional increase of the skin friction drag due to roughness is the same as that for a flat plate. It follows that the fractional increase in profile drag will also be the same.

Before an attempt can be made to apply Nikuradse's results to the determination of the effect on the drag of an aircraft of a roughness different from sand roughness, such as camouflage paint, two important queries must be answered:—

(*a*) What is the sand roughness height equivalent to the roughness under consideration?

(*b*) How does this equivalent sand roughness height vary with Reynolds number?

The work described in this paper was concerned with answering these queries for camouflage paint roughness. It must be emphasised that only the drag increase due to

the increase of the frictional drag in the turbulent boundary layer was investigated, the separate problem of the drag effect due to transition point movement caused by the roughness was not considered.

The tests were made in the High Speed Tunnel of the Royal Aircraft Establishment in 1944.

2. DESCRIPTION OF TESTS

The tests were made on a metal covered wing of NACA 0012 section at zero incidence. Wires to provoke transition were fixed at 0.1c behind the leading edge on both surfaces. Drag measurements were made by the well-known pitot traverse method developed by Prof. Sir B. M. Jones, but modified to allow for compressibility effects[5, 6]. In addition to measurements of the drag of the unpainted wing, measurements were made of the drag of the wing covered with five different paint finishes of varying roughness, applied from the wires to the trailing edge. These were classified as follows—

Paint No.	*Remarks*
1.	This represented the smoothest matt finish attainable with standard day camouflage paint, carefully prepared and applied.
2.	This represented standard day camouflage paint, applied with average care and skill.
3.	This represented day camouflage paint, carelessly applied.
4.	This represented special night paint, applied with moderate care.
5.	This was not a standard paint, but was specially prepared to give a very rough finish, with a roughness height of the order of 0.01 in.

In each case the drag was measured over a range of Reynolds numbers from about 4.5×10^6 to about 15×10^6 at a constant Mach number of 0.2, and over a range of Mach numbers from 0.2 to about 0.7 at a constant Reynolds number of 4.5×10^6, and from 0.2 to about 0.6 at a constant Reynolds number of 6.0×10^6. The object was to separate scale effects from the effects of compressibility for Mach numbers less than the critical. Preliminary tests were first made to check that the wires caused transition for all the cases to be covered, and it was found that due to scratchings and pittings that had developed over the leading edge of the wing during the initial tests, transition was occuring ahead of the wires and practically at the leading edge in every case.

For each finish tested a number of roughness records were taken by means of a roughness gauge developed by Dr. Tomlinson, of the National Physical Laboratory. With this gauge the excrescences are explored by means of a fine probe, whose movements are magnified by means of a system of levers and eventually transferred to a stylo scratching lightly over the surface of a smoked glass plate. The record obtained can then be enlarged optically. The total traverse of this gauge is 7 in. and takes about 10 minutes to make. The gauge is therefore particularly suitable for this kind of work, as a few sample records are usually sufficient to give a representative picture of a roughened surface.

3. DISCUSSION

Figures 2 and 3 show the drag coefficients measured at constant Reynolds numbers of 4.5×10^6 and 6.0×10^6, respectively, plotted as functions of the Mach number. It will be noted that in each case the curves for the different finishes tested are substantially parallel lines. This leads to the interesting conclusion that for Mach numbers less than the critical, compressibility has no effect on the drag increase due to roughness. The effect of roughness on the critical and the shock stalling Mach numbers is a separate problem which was not investigated in these tests.

Figure 4 shows the drag coefficients measured at a constant Mach number of 0.2

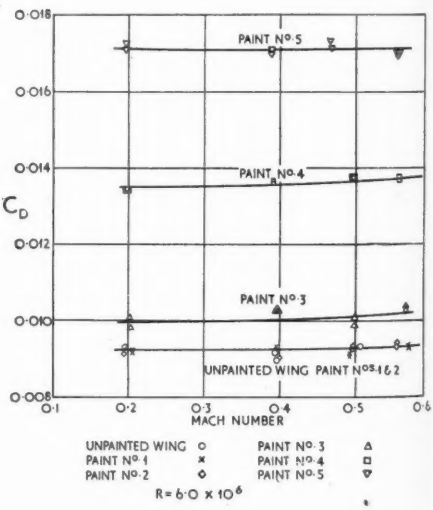


Fig. 2.

plotted as functions of the Reynolds numbers. Paint No. 1 finish is aerodynamically smooth at least up to a Reynolds number of about 12×10^6, while Paint No. 2 finish is aerodynamically smooth up to a Reynolds number of about 8×10^6. The interesting features of the other curves are the more rapid rise of the drag coefficient with the Paint No. 3 finish at the higher Reynolds numbers, and the contrastingly slow increases of drag coefficient with the Paint Nos. 4 and 5 finishes. It is clear that at about 12×10^6 the flow over the Paint No. 4 finish is effectively fully developed roughness flow, the same is true of the Paint No. 5 finish over the whole Reynolds number range tested.

These results are qualitatively much what would be expected in the light of Nikuradse's experiments. It remained to be seen, therefore, whether there was a basis on which quantative agreement could be found. For each finish, the equivalent sand roughness height K_e was estimated at Reynolds numbers of 5×10^6, 10×10^6 and 15×10^6 from the corresponding increases in drag coefficient over that of the unpainted wing. The process was as follows. The increase was first multiplied by the factor 10/9, on the assumption that it would then correspond to the increase in the drag coefficient if the boundary layer had been turbulent from the leading edge and the paint had been applied to the whole wing instead of the rear ninetenths of the wing*. This augmented increment was then divided by the theoretical drag coefficient of the smooth wing with transition at the leading edge to give the

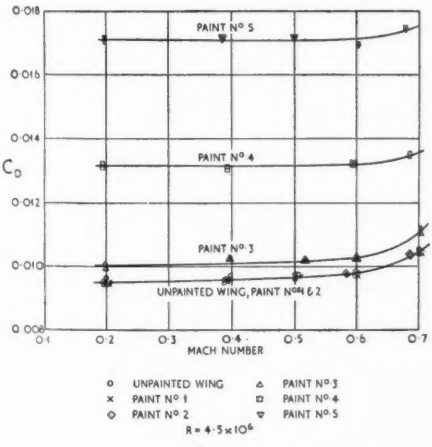


Fig. 3.

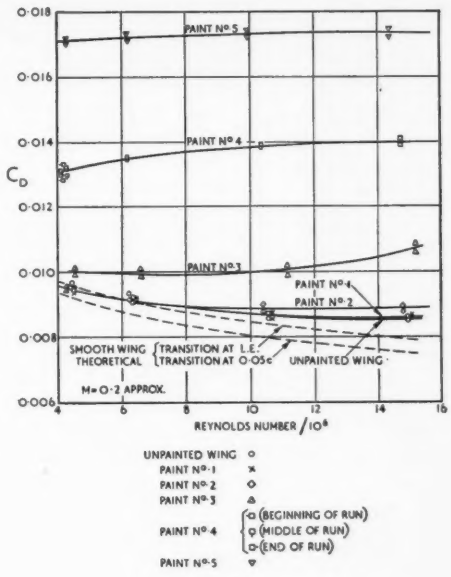


Fig. 4.

ratio which, in effect, is $\Delta D/D$ in Fig. 1. From the value of this ratio and the chosen Reynolds number the corresponding value of l/K_e was then obtained from Fig. 1, and hence the equivalent sand roughness height K_e was obtained. It was gratifying to find that for the range of Reynolds numbers tested the variation of K_e for each roughness with Reynolds number was small enough to be neglected. Table I includes a summary of the mean values of K_e obtained for the roughnesses tested.

It may be noted that the accuracy of the value of K_e for Paint No. 1 depends on the accuracy of the measurements of the small differences in drag between the surface with Paint No. 1 and the unpainted wing at the

*In assessing the probable increase in the drag coefficient due to painting the first ten per cent. of the wing, two opposing factors had to be taken into account. The boundary layer being thinner near the leading edge, the rate of drag increase with surface painted might be expected to be greatest there. On the other hand the velocity over an appreciable part of the first ten per cent. of the surface is low, and this might be expected to reduce the rate of drag increase. It was decided therefore that no serious errors were likely to be involved in assuming that the rate of drag increase with surface painted for the first ten per cent. of the wing surface was the same as the average rate for the remaining ninety per cent.

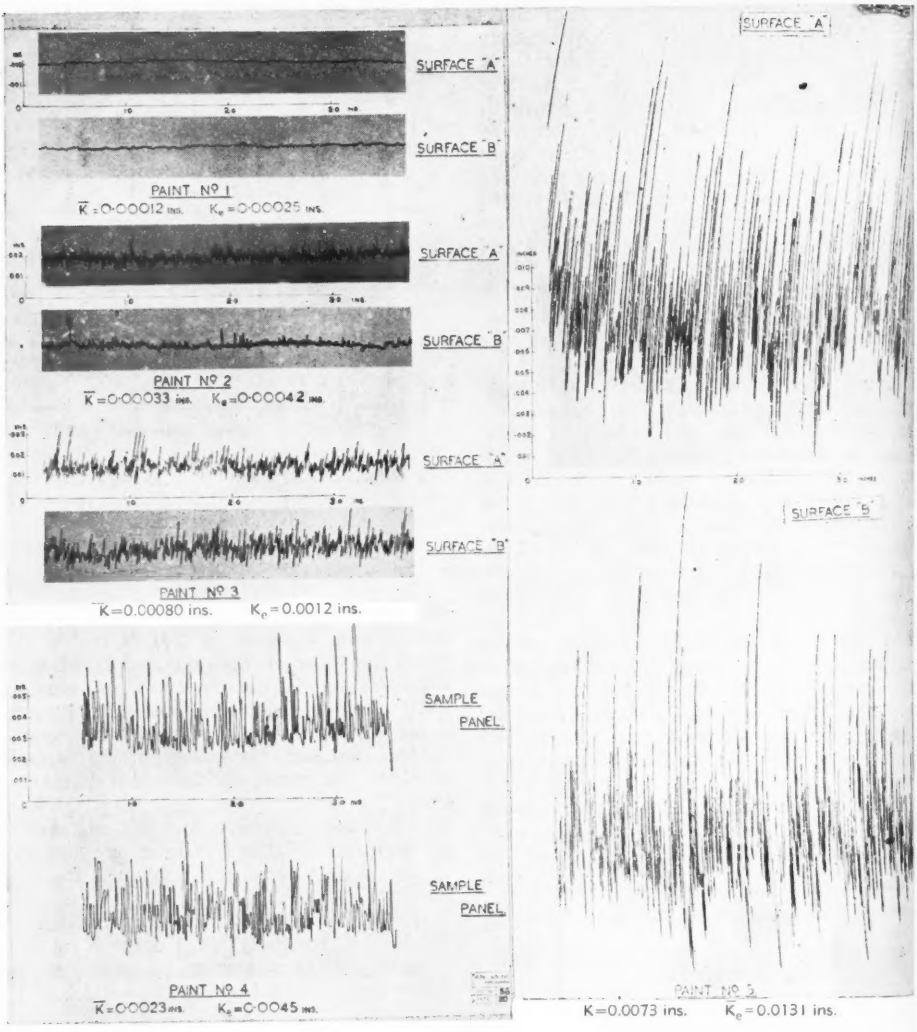


Fig. 5.

Specimen records of paint roughness made with Tomlinson Gauge No. 2.

higher Reynolds numbers, and these differences were almost within the order of accuracy of the measurements. Its probable error treated as a fraction of its true value therefore, is greater than that for the other paints examined.

Figure 5 shows some samples of the roughness records taken of the various finishes. For each of the finishes a mean roughness height ($\bar{K}$) was obtained by measuring the normal height from trough to crest for each excrescence of its records and averaging the measurements. It is realised that this mean roughness height does not give full information about a particular surface, but it is a useful parameter for classifying roughnesses that are physically similar, as are camouflage paint roughnesses. Table I summarises the

values of $\overline{K}$ obtained and in the last column are shown the corresponding values of $K_e/\overline{K}$.

TABLE I

Paint No.	$\overline{K}$ (*in.*)	K_e (*in.*)	$K_e/\overline{K}$
1	0.00012	0.00025	2.08
2	0.00032	0.00042	1.31
3	0.00080	0.0012	1.50
4	0.0023	0.0045	1.96
5	0.0073	0.0131	1.79

Disregarding the value of this ratio for Paint No. 1 because of the relatively poor accuracy of the value assessed for K_e, it is noted that for the remaining surfaces tested $K_e/\overline{K}$ is roughly about 1.6. It is by no means surprising that the mean roughness height is considerably smaller than the equivalent sand roughness height. Experiments of Schlichting[7] have shown that there is an optimum spacing of excrescences of a given height for maximum drag effect, and this spacing is considerably more open than that corresponding to the closest packing possible. For closer spacing than the optimum the shielding effect of the excrescences on each other becomes important, suppose then, that between large excrescences at this optimum spacing a number of much smaller excrescences are packed. The net effect on the drag would be slight but the mean roughness height may be considerably reduced. This suggests therefore that the effective roughness height of a surface would be heavily weighted in favour of the larger excrescences present on it. If the roughness records of Fig. 5 are examined it is seen that in every case roughnesses of the order of the equivalent sand roughness height occur with fair frequency*. In fact, if an attempt is made to estimate the average roughness by eye from a record, a figure is arrived at much nearer the equivalent sand roughness height than is the calculated mean roughness value. This is because the eye is dominated by the records of the larger roughnesses that occur with reasonable frequency and takes little note of the very small excrescences that effectively reduce the value of the arithmetic mean roughness height.

Three processes suggest themselves, therefore, for deriving the equivalent sand roughness height from a set of records obtained by a roughness gauge of the Tomlinson type on a camouflage painted surface:—

(1) Treat the record shown in Fig. 5 as a scale against which to compare the records under consideration. It should then be possible to estimate the equivalent roughness height with reasonable accuracy.

(2) Determine the arithmetic mean roughness height ($\overline{K}$) and multiply by the factor 1.6.

(3) Accept the height of the largest roughnesses that can be said to occur with fair frequency as the equivalent sand roughness height.

Of these processes the first is the most reliable; the other two are liable to an error of the order of ± 25 per cent.

4. APPLICATION

Having established the equivalent sand roughness heights, the curves of Fig. 1 can now be used to predict the effect of the various finishes tested on the drag of wings and bodies, for a range of wing chord or body lengths (l), forward speeds and heights. The results of such calculations are shown in Fig. 6 for values of l ranging from 5 ft. to 100 ft., forward speeds up to 600 m.p.h. (true) and heights of 0, 20,000 ft. and 40,000 ft.*

By way of illustration, these curves have been used to estimate the effect of the paints on the top speeds of aeroplanes of representative dimensions, namely, a single-seater aircraft of about 40 ft span, capable when aerodynamically smooth of either 450 m.p.h. at 20,000 ft. or 550 m.p.h. at 40,000 ft., and a four-engined aircraft of about 100 ft. span capable of 350 m.p.h. at 20,000 ft., or 450 m.p.h. at 40,000 ft. The results are summarised in Table II.

TABLE II

Description	*Ht. (ft.)*	*Top speed (smooth state) m.p.h.*	*Reduction in top speed (m.p.h.) due to Paint*				
			1	*2*	*3*	*4*	*5*
Single-seater	20,000	450	0	0	11	50	79
(span 40 ft.)	40,000	550	0	0	4½	44	82
4-engined	20,000	350	0	0	4½	28	49
aircraft	40,000	450	0	0	1½	26	50
(span 100 ft.)							

*This was even more clearly demonstrated by frequency histograms of the roughnesses, which have not been reproduced in this paper.

*It will be clear from the derivation of these curves that to apply them the basic (smooth surface) drag must not include any drag due to shock wave energy losses or flow break away.

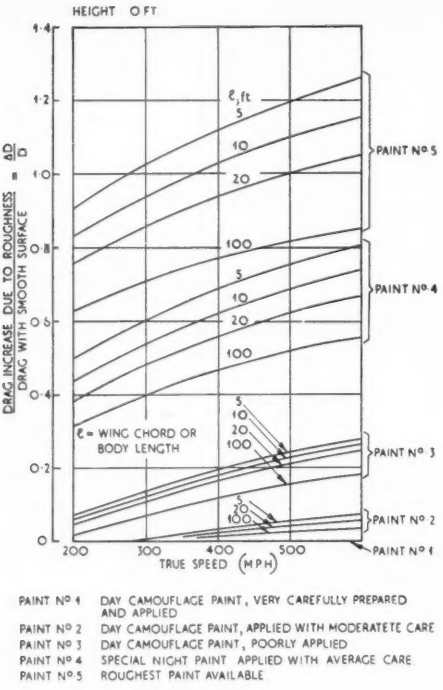

HEIGHT O FT
DRAG INCREASE DUE TO ROUGHNESS / DRAG WITH SMOOTH SURFACE = ΔD/D
TRUE SPEED (M.P.H)
ℓ, ft
ℓ = WING CHORD OR BODY LENGTH
PAINT No 5
PAINT No 4
PAINT No 3
PAINT No 2
PAINT No 1
PAINT No 1 DAY CAMOUFLAGE PAINT, VERY CAREFULLY PREPARED AND APPLIED
PAINT No 2 DAY CAMOUFLAGE PAINT, APPLIED WITH MODERATETE CARE
PAINT No 3 DAY CAMOUFLACE PAINT, POORLY APPLIED
PAINT No 4 SPECIAL NIGHT PAINT APPLIED WITH AVERAGE CARE
PAINT No 5 ROUGHEST PAINT AVAILABLE

Fig. 6.

These estimates are based on the simple assumption that the power is constant, changes in boost and rated altitude being neglected. Further, allowance has been made for proportionate increases in interference drag accompanying the increases of frictional drag.

It is interesting to note that neither Paint No. 1 nor No. 2 cause any drag increase in the examples considered. This leads to the conclusion that if the surface finish is equivalent to that obtained with standard day camouflage applied with care no serious adverse effects on performance and speed need be expected, even for aircraft flying at relatively high speeds. It will be noted that the permissible tolerance on the finish becomes smaller the lower the altitude at which the aircraft operates.

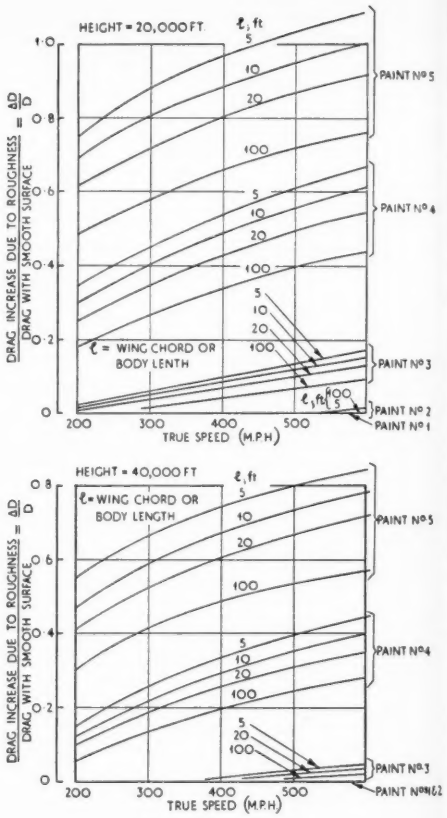

HEIGHT = 20,000 FT
HEIGHT = 40,000 FT
DRAG INCREASE DUE TO ROUGHNESS / DRAG WITH SMOOTH SURFACE = ΔD/D
TRUE SPEED (M.P.H)
ℓ, ft
ℓ = WING CHORD OR BODY LENTH
PAINT No 5
PAINT No 4
PAINT No 3
PAINT No 2
PAINT No 1

Fig. 6 (*continued*)

References

1. Nikuradse. Forschungsheft No. 361 (1933). *See also Aerodynamic Theory* (Durand), Vol. III.
2. Prandtl and Schlichting. Werft Reederel Hafen (1934). *See also Aerodynamic Theory* (Durand), Vol. III.
3. Squire and Young. The Calculation of the Profile Drag of Aerofoils. R. & M. 1838 (1937).
4. Young. The Calculation of the Total and Skin Friction Drags of Bodies of Revolution at Zero Incidence. R. & M. 1874 (1939).
5. Cambridge University Aeronautics Laboratory. Measurements of Profile Drag by the Pitot-Traverse Method. R. & M. 1688 (1936).
6. Young. Note on the Effect of Compressibility on Jones' Momentum Method of Measuring Profile Drag. R. & M. 1881 (1939).
7. Schlichting. Ingenieurarchiv (1936).

SITING OF LANDING STRIPS FOR INTERNATIONAL AIRCRAFT MOVEMENTS IN GREAT BRITAIN

by

WILLIAM COURTENAY, O.B.E., M.M., A.R.Ae.S.

AIR travel at 600 m.p.h. to 650 m.p.h. in the next decade and the use of multi-seat twin rotor helicopters on internal air routes to help to solve terminal delay problems, bring in their train growing problems of Air Traffic Control. Full use of high speed civil transports and helicopters does not seem practicable within the British Isles unless the problem of the siting of landing strips is reviewed and unless ideas on this subject are recast in the light of growing experience.

To the commercial airline pilot Great Britain is indeed a "tight little island." It will appear smaller yet when the de Havilland Comet jet air liner operates to time-tables of approximately double the speed of most of the existing schedules of today. It will shrink still farther when the next phase of jet powered air liners, which may be designed by 1953 and in full use by 1960, provide time-table speeds of 600 to 650 m.p.h.

Air liners of today, flying at 300 m.p.h. cross England at its greatest width in little more than 30 minutes and the normal time for direct flights from Prestwick Airport, Scotland to London Airport, is only some 90 minutes.

In conditions of poor visibility when air liners have to be guided in to London Airport or Northolt Airport by Instrument Approach, they sometimes have to wait and be "stacked up" in a wide area round the Metropolis at varying heights, with 1,000 ft. vertical intervals between aircraft, each awaiting a landing turn. This creates grave and growing problems for the Air Traffic Controllers and, as the volume of traffic grows, more and more devices, including Radar, are being pressed into service in an endeavour to bring the air liners to safe anchorage with a minimum of delay, of stacking, of orbiting and of danger.

The more intricate the system of Air Traffic Control grows, the more does ultimate safety depend on absolute obedience and discipline from the pilot and on the "human factor" of those operating on the ground. The picture of many air liners flying round built-up areas and of a queue stretching perhaps from London to the south coast cannot be viewed with equanimity.

The ingenuity displayed and the organising genius employed in preparing the present traffic pattern command respect and admiration, but any solution of the problem of the future on present lines can only be achieved at the expense of complete loss of the "freedom of the air" over much of the British Isles. In addition, the increased consumption of fuel, wear and tear of engines, and the rising operating costs therefrom, all resulting from the present system of queueing, add to the passenger fare.

British Overseas Airways Corporation has estimated that normal flying operations of the Bristol Brabazon II may cost £400 an hour. One hour's delay in landing because of queueing will add £400 to the cost of an inbound voyage. This is equivalent to a premium of £4 a head, if 100 passengers are carried.

There must be an alternative, however drastic in conception, to the present method of control and of landings. As the speeds of air liners increase and jet and prop-jet

Paper received April 1950.

aircraft are introduced, and as the frequency of schedules increases with the growing popularity of air travel, the problem may well defeat those who are trying to find a solution to it. The correct solution would appear to be to restore the "freedom of the air" above the towns and countryside by the removal of almost every class of fixed-wing air liner from airports in the vicinity of cities.

Ships of the ocean-going steamship services do not expect berthing arrangements in the centre of a city; they anchor as soon as they reach harbours on the coasts and they prepare for such anchorage as soon as the coastline is within sight. It would seem that air liner traffic ultimately must follow suit because of the limited size of the British Isles; their crowded condition, the size of the population and distribution of cities, and above all, the vagaries of a climate which introduces so many complications.

If, instead of directing all air traffic towards one airport close to London, it were separated and dispersed to air strips on the south, east and west coasts, many advantages would accrue, including the following:—

(*a*) The "freedom of the air" would be restored to Light Aeroplane Clubs and to the private owner.

(*b*) The Royal Air Force, at present perplexed about its training areas in Great Britain because of air liner movements in Southern England, would be given more room for manœuvre.

(*c*) Pilots would begin their "let-down" procedure over the sea, knowing that there were no obstacles or built-up areas in the track of descent.

(*d*) Commercial aircraft would no longer cause annoyance to householders by operating, especially at nights, close to their homes.

(*e*) The ceiling under which Instrument Approach Landings could be completed might be lowered with safety with a consequent increasing schedule of flights satisfactorily completed, because the air liner would be approaching from the sea to an anchorage at the shoreline.

(*f*) Queueing would not be required since, with the provision of several air strips along a coast, traffic could be diverted as weather conditions dictated, allowing a higher percentage of visual contact landings than there are at present.

(*g*) The whole problem of Air Traffic Control would be eased.

(*h*) The inland areas of the British Isles would be left clear for the full development of helicopter services.

Under this plan there would be a number of landing strips on the west coast of England and Scotland for traffic to and from the Western Hemisphere; air liners on these routes normally cross the west coast on their approach to London. In this connection the existing landing strip at Filton Aerodrome, Bristol, as well as the commercial airports at Cardiff, Liverpool and Prestwick, would be useful. They should be reinforced by the provision of a number of new strips facing westwards. Consideration might be given to their construction from a harbour seawards. The harbour could then provide flying-boat facilities with helicopter services for the rapid conveyance of passengers to London or other destinations.

On the south coast a number of long landing strips should be laid down for all traffic from the Middle East, India, South Africa and Australasia. On the east coast similar strips in Lincolnshire, Yorkshire, Essex and Scotland would be required for the more distant Continental services.

These landing strips should be provided with minimum facilities only, such as fueling facilities, and cover for the transfer in bad weather of passengers, baggage, mails and freight to waiting helicopters. Broad roads of an "autobahn" character should connect the air strips with main highways.

Passengers would be transferred at once, without formality, from the incoming air liner at the coastal air strip, to waiting helicopters. These would convey them to the city of their destination where Customs, Health and Immigration authorities could be waiting. Thus traffic would first be dispersed among many coastal landing strips and secondly, dispersed among many cities of destination or, several helicopter sites in a large city such as London. By this plan dispersal, instead of concentration, would become the key to safer landings, a smooth traffic flow and the rapid disposal of passengers and baggage. As speeds increase rapid handling becomes of prime importance.

The passengers of a jet-propelled air liner of 1960 which may cross non-stop from New York to London in five hours, will feel acutely the expenditure of another 60 minutes in waiting in a queue for a landing

turn in bad weather or spending an hour passing through Customs, Immigration, Health and other administrative checks. This 60 minutes' terminal delay may not appear to be so great after an ocean flight lasting fifteen hours, but as the elapsed time shrinks, so does terminal delay become interminable.

Such a plan for dispersal of commercial air liners to the coasts could only operate in conjunction with a helicopter service capable of handling all traffic to and from London, other cities, and the coastal landing strips.

At present a helicopter attempting to operate a scheduled service on an internal air route is kept earthbound if its point of departure is in a Traffic Controlled Zone. This is because incoming air liners flying under Instrument Control in conditions of reduced visibility must be given priority. Thus the helicopter must await its turn for take-off and landing. If the fixed-wing air liner is moved to the coast, the air becomes clear for the full development of inter-city helicopter services.

It may be assumed that all the cross-channel air services between British cities and Paris, Brussels, Amsterdam and other centres not more than 300 miles away by air from British cities, will change over from fixed-wing to helicopter services by 1960. It has been calculated that even the 100 m.p.h. helicopter can set down its passengers in a city centre up to 300 miles distance from point of departure, more rapidly than an air liner cruising at 300 m.p.h. Terminal delay at either end of the air journey would absorb up to 45 minutes of road travel. During that total of 90 minutes the helicopter would have covered at least a third of its journey.

Since the bulk of the heavy traffic from the Continent arriving in, or departing from, London is cross-channel traffic, the Air Traffic Controllers would be relieved of a considerable burden once this traffic was helicopter-borne.

There would remain the medium-distance traffic. Air liners flying 700 to 1,000 miles would be operating distances which were too short to warrant a halt at the coast and too long to enable the helicopter at destination to cut the journey time appreciably. Traffic from the Scandinavian countries, Berlin, points East, the Balkans, Spain, Portugal, and Turkey could still be routed to London Airport. Its volume might be such as to cause no inconvenience to the R.A.F. operating in the south; or insufficient to interfere with Light Aeroplane Club activities or helicopter services, while the volume would be more than sufficient to justify the capital costs sunk in the development of London Airport.

REVIEWS

AVIATION MEDICINE—ITS THEORY AND PRACTICE. K. G. Bergin. J. Wright & Sons, Bristol. 1949. 448 pp. 120 illustrations. 35s. net.

This book covers a wide field of subjects and the space devoted to them does not appear to be related to their respective importance in the field of Aviation Medicine. The bulk of the subject matter and illustrations have been taken from previously published authoritative publications.

Purported to be the first work to cover such a range of subjects, this book can claim originality in its omission of much important data and the inclusion of not a few inaccuracies.

While in his Preface the author states that this book is intended for the medical profession, it is to be hoped that the chapter on diet and nutrition may not reach the travelling public or those concerned with catering matters in civil aviation. To feed passengers *2-hourly* on the menus suggested would, it is felt, embarrass the ingenuity of not only the caterer but also those engaged in the intricacies of the remaining payload and revenue potentials after all accoutrements essential for the comfort of the passenger have been deducted. Nevertheless this book is likely to have a market among lay readers desirous of having an acquaintance with the author's subjects.

The book has been well presented by the publishers. The good quality paper and clear type indicates a return to the high pre-war standard for which they were renowned. The illustrations are good and well produced.

THERMODYNAMICS APPLIED TO HEAT ENGINES. E. H. Lewitt. Pitman & Sons Ltd. London. 1950. Fourth Edition. 750 pp. Index. Illustrated. £1 10s. net.

In the fourth edition of this well-known book, the author has revised the text, and made considerable additions to bring it up to date. Several new chapters have been added dealing with recent developments. The gas turbine is considered, both as a jet propulsion unit for aircraft, and applied to industrial purposes, some space being devoted to various gas turbine cycles. As rotational speeds have increased and the uses of the cathode ray oscilloscope developed, the technique of measurement of rapidly fluctuating pressures has altered considerably, and one new chapter is devoted to developments in this field. Other new features include chapters dealing with rotary compressors, present day problems in the combustion process in I.C. engines, and modern steam plant practice.

For readers not familiar with this work, one may say that it is comprehensive and deals with practically all aspects of Heat Engines and Thermodynamics. The opening chapters are devoted to general thermodynamics, followed by a chapter on reciprocating air compressors. From here, the author proceeds to the properties of steam, and the theory of the steam engine and turbine. Problems of refrigeration are dealt with, and after discussing the properties of various fuels, internal combustion engines are considered in some detail. Some space is devoted to the kinetic theory of gases and the effects of the variation of their specific heats with temperature, large scale total heat/entropy charts for air being included in the text.

Generally speaking, this is a very useful text-book, although one would have liked to see the gas turbine, which is rapidly becoming of increasing importance, considered in greater detail. In this connection, where the gas velocities approach sonic conditions, more information on compressible flow and Mach number effects would have been useful.

The author has certainly succeeded in his attempt to provide a text-book covering the syllabuses for the B.Sc.(Eng.) and the Institution of Mechanical Engineers' examinations in this subject. A useful feature in this respect is the list of examples taken from appropriate examination papers at the end of each chapter.

The book is well set out and printed on good quality paper, and considering its size, not expensive at thirty shillings.

an appreciation

THE COUNCIL OF THE ROYAL AERONAUTICAL SOCIETY WISH TO THANK THOSE COMPANIES WHO, BY THEIR GENEROUS CO-OPERATION, HAVE DONE SO MUCH TO HELP IN THE PRODUCTION OF THE JOURNAL

AEROPLANE & MOTOR ALUMINIUM CASTINGS LTD.

ALUMINIUM GRAVITY DIE CAST CYLINDER HEAD

SIR W. G. ARMSTRONG WHITWORTH AIRCRAFT LTD.

SIR W. G.
ARMSTRONG WHITWORTH
AIRCRAFT LIMITED

AIRCRAFT MATERIALS LTD.

AML

STRUCTURAL MATERIALS and COMPONENTS

AUTOMOTIVE PRODUCTS CO. LTD.

ALL-BRITISH Lockheed

hydraulics

AIRWORK LTD.

AIRWORK LIMITED

AVIATION DEVELOPMENTS LTD.

AVIATION DEVELOPMENTS LTD
KINGSBOURNE HOUSE
HIGH HOLBORN, LONDON WC1
Specialists in Blind Riveting and Fastening Devices

ARMSTRONG SIDDELEY MOTORS LTD.

ARMSTRONG SIDDELEY

BLACKBURN & GENERAL AIRCRAFT LTD

BLACKBURN & GENERAL

BOULTON PAUL AIRCRAFT LTD.

BPA

DUNLOP RUBBER CO., LTD.

DUNLOP

THE BRISTOL AEROPLANE CO., LTD.

"Bristol"

ELECTRO-HYDRAULICS LTD.

EH LIMITED

BROOM & WADE LTD.

"BROOMWADE"

AIR COMPRESSORS AND PNEUMATIC TOOLS

THE ENGLISH ELECTRIC CO. LTD. LONDON

'ENGLISH ELECTRIC'

MANUFACTURERS OF AIRCRAFT, AIRCRAFT ELECTRICAL EQUIPMENT, WIND TUNNEL DRIVES, TEST PLANTS FOR RECIPROCATING AND TURBINE-TYPE ENGINES, SUPERCHARGERS, COMPRESSORS, ETC.

DOWTY EQUIPMENT LTD.

DOWTY

UNDERCARRIAGE AND HYDRAULIC EQUIPMENT

THE FAIREY AVIATION CO. LTD.

FAIREY

HIGH-PERFORMANCE SERVICE AIRCRAFT

DUNFORD & ELLIOTT (SHEFFIELD) LTD.

Dunelt Special steels FOR AIRCRAFT

FIRTH-VICKERS STAINLESS STEELS LTD.

"Staybrite Steel"

FOLLAND AIRCRAFT LTD.

FOLLAND AIRCRAFT LTD.

HAMBLE, SOUTHAMPTON

H. M. HOBSON LTD.

Hobson

GLOSTER AIRCRAFT CO., LTD.

GLOSTER AIRCRAFT CO. LTD.

F. A. HUGHES & CO. LTD.

Distributors of

ELEKTRON

REGISTERED TRADE MARK

MAGNESIUM ALLOYS

HANDLEY PAGE LIMITED

HP

THE HUGHES-JOHNSON STAMPINGS LTD

JH

HAWKER AIRCRAFT LTD.

HAWKER

HYMATIC ENGINEERING CO. LTD.

Hymatic

COMPRESSED AIR EQUIPMENT

THE HESTON AIRCRAFT CO., LTD.

HESTON AIRCRAFT

IMPERIAL CHEMICAL INDUSTRIES LTD.
(METALS DIVISION)

ICI

INTEGRAL LTD.

INTEGRAL
HYDRAULIC PUMPS AND EQUIPMENT

LIGHT-METAL FORGINGS LTD.

LMF

IRVING AIR CHUTE OF GREAT BRITAIN LTD.

AIR CHUTES
IRVIN

LODGE PLUGS LIMITED

LODGE
AVIATION
SPARKING PLUGS

K.L.G. SPARKING PLUGS LTD.

K·L·G
SPARKING PLUGS AND IGNITION EQUIPMENT

MARTIN-BAKER AIRCRAFT CO. LTD.

MB

KELVIN & HUGHES (AVIATION) LTD.

REGISTERED TRADE MARK
HUSUN
HENRY HUGHES & SON LTD LONDON

(HENRY HUGHES & SON LTD.)

D. NAPIER & SON LTD.

N

KELVIN & HUGHES (AVIATION) LTD.

KBB

(KELVIN BOTTOMLEY & BAIRD LTD.)

NORMALAIR LIMITED

NORMALAIR

THE PALMER TYRE LTD.

'First in the Air'

Palmer

Penfold Street, Edgware Road, London, N.W.8

ROLLS-ROYCE LTD.

ROLLS-ROYCE

AERO-ENGINES

PERCIVAL AIRCRAFT LTD.

ROTAX LTD.

ROTAX

AIRCRAFT ELECTRICAL ENGINEERS

PETO & RADFORD

DAGENITE

AIRCRAFT BATTERIES

SAUNDERS-ROE LTD.

SAUNDERS-ROE LTD

OSBORNE, EAST COWES, ISLE OF WIGHT

Telephone: Cowes 445

THE PULSOMETER ENGINEERING CO. LTD.

Pulsometer

FUEL PUMPS FOR AIRCRAFT

SELF-PRIMING PUMP AND ENGINEERING CO. LTD.

SPECIALISTS *in* *Aircraft Fuel Line Equipment*

A. V. ROE & CO. LTD.

AVRO

SERCK RADIATORS LTD.

SERCK

SHORT BROTHERS & HARLAND LIMITED

Shorts

Established 1908

THE FIRST MANUFACTURERS OF AIRCRAFT IN THE WORLD

THE UNITED STEEL COMPANIES LIMITED

"FLYING FOX"
ELECTRIC STEELS

S. FOX & CO. LTD. SHEFFIELD

SKYHI LTD.

SKYHI

VOKES LTD.

AMBER CROSS
TRADE MARK
Symbol of complete protection by Vokes Filters

SMITHS AIRCRAFT INSTRUMENTS LTD.

SMITHS

WESTLAND AIRCRAFT LTD.

WESTLAND AIRCRAFT LIMITED
Yeovil, Somerset

THE SPERRY GYROSCOPE CO. LTD.

SPERRY

A. C. WICKMAN LTD.

A.C. Wickman LIMITED
COVENTRY • ENGLAND •

SPECIALISTS IN MACHINE TOOLS & SMALL TOOLS FOR THE AIRCRAFT INDUSTRY

STERLING METALS LIMITED

STERMET
REGD TRADE MARK

YORKSHIRE ENGINEERING SUPPLIES LTD.

BRONZE FOUNDRIES

YESEATONIA

BEARINGS AND BUSHES

DIRECTORY OF ADVERTISERS

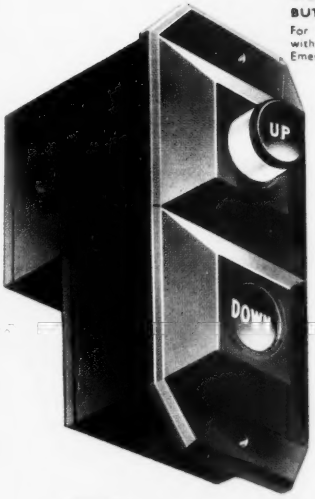
ACCLES & POLLOCK LTD.	Paddock Works, Oldbury, Birmingham	Broadwell 1500
AEROPLANE & MOTOR ALUMINIUM CASTINGS LTD.	Wood Lane, Erdington, Birmingham	Erdington 2207-9
AIRCRAFT MATERIALS LTD.	Midland Road, London, N.W.1	Euston 6151
AIRSPEED LTD.	The Airport, Portsmouth	Portsmouth 74631
AIRWORK LTD.	15 Chesterfield Street, London, W.1	Grosvenor 4841
ALBRIGHT & WILSON LTD.	49 Park Lane, London, W.1	Grosvenor 1311
ALVIS LTD.	Holyhead Road, Coventry	Coventry 5501
ARMSTRONG SIDDELEY MOTORS LTD.	Parkside, Coventry	Coventry 4061
ARMSTRONG WHITWORTH AIRCRAFT, SIR W. G., LTD.	Whitley, Coventry	Tollbar 2261 (15 lines)
AUTOMOTIVE PRODUCTS CO. LTD.	Tachbrook Road, Leamington Spa	Leamington Spa 1700
AVIATION DEVELOPMENTS LTD.	229 High Holborn, London, W.C.1	Chancery 8601
AVICA EQUIPMENT LTD.	50 Pall Mall, London, S.W.1	Trafalgar 5505-6-7
BIRMINGHAM ALUMINIUM CASTING (1903) CO. LTD.	Birmid Works, Smethwick, Birmingham, 40	Smethwick 1431
BLACKBURN AND GENERAL AIRCRAFT LTD.	Head Office: Brough, E. Yorks.	Brough 121
	Feltham Factory: Feltham, Middlesex	Feltham 3636
	London Office: 43 Berkeley Square, W.1	Grosvenor 5771-8
BOOTH, JAMES & CO. LTD.	Argyle Street Works, Nechells, Birmingham, 7	Birmingham E. 1221
BOULTON PAUL AIRCRAFT LTD.	Wolverhampton, Staffs.	Fordhouses 3191
BRISTOL AEROPLANE CO. LTD., THE	Filton House, Bristol	Bristol 48051
BRITISH BELTING AND ASBESTOS LTD.	Cleckheaton, Yorks.	Cleckheaton 800
	59 Southwark Street, London, S.E.1	Hop. 0192
BRITISH MESSIER LTD.	Cheltenham Road East, Gloucester	Churchdown 3281
BRITISH OVERSEAS AIRWAYS CORPORATION	Headquarters: Stratton House, Stratton Street, W.1	Mayfair 6611
	Traffic Enquiries: Airways Terminal, Buckingham Palace Road, S.W.1	Victoria 2323
BRITISH THOMSON-HOUSTON CO. LTD.	Lower Ford Street, Coventry	Coventry 4104
BROOM & WADE LTD.	High Wycombe, Bucks.	High Wycombe 1630
DE HAVILLAND AIRCRAFT CO. LTD., THE	Hatfield Aerodrome, Herts.	Hatfield 2345
DOWTY EQUIPMENT LTD.	Cheltenham, Glos.	Cheltenham 53471
DOWTY SEALS LTD.	Cheltenham, Glos.	Cheltenham
DUNFORD & ELLIOTT (SHEFFIELD) LTD.	Attercliffe Wharf Works, Sheffield, 9	Sheffield 41121-4
DUNLOP RUBBER CO. LTD.	Fort Dunlop, Erdington, Birmingham, 24	Erdington 2121
ELECTRO-HYDRAULICS LTD.	Liverpool Road, Warrington	Warrington 2244
ENGLISH ELECTRIC CO. LTD.	Queens House, Kingsway, London, W.C.2	Holborn 6966
	Stafford	Stafford 700
FAIREY AVIATION CO. LTD.	Hayes, Middlesex	Hayes 3800
FIRTH, THOS. AND JOHN BROWN LTD.	Atlas and Norfolk Works, Sheffield, 1	Sheffield 20081, 26491
FIRTH-VICKERS STAINLESS STEELS LTD.	Staybrite Works, Sheffield	Sheffield 42051
FLIGHT REFUELLING LTD.	5 Clarges Street, London, W.1	Grosvenor 5741
	Tarrant Rushton Airfield, Blandford, Dorset	Blandford 501
FOLLAND AIRCRAFT LTD.	Hamble, Southampton, Hants.	Hamble 3191
GLOSTER AIRCRAFT CO. LTD.	Gloster Works and Aerodrome, Hucclecote, Glos.	Gloucester 66294
GRAVINER MANUFACTURING CO. LTD.	(Aircraft Division Sales Dept.), Poyle Mill Works, Colnbrook, Bucks.	Colnbrook 48-49
HANDLEY PAGE LTD.	Cricklewood, London, N.W.2	Gladstone 8000
HAWKER AIRCRAFT LTD.	Canbury Park Road, Kingston-on-Thames	Kingston 1044
HESTON AIRCRAFT CO. LTD., THE	Heston Airport, Middlesex	Southall 2321
HIGH DUTY ALLOYS LTD.	Slough, Bucks.	Slough 21201
HOBSON, H. M., LTD.	Hobson Works, Fordhouses, Wolverhampton	Fordhouses 2266
HUGHES, F. A., & CO. LTD.	Bath House, 82 Piccadilly, London, W.1	Grosvenor 6300
HUGHES, HENRY & SON, LTD.	Husun Works, New North Road, Barkingside, Essex	Hainault 2601
HUGHES-JOHNSON STAMPINGS LTD., THE	Langley Green, Birmingham	Broadwell 1361
HYMATIC ENGINEERING CO. LTD.	Redditch, Worcestershire	Redditch 743
ILIFFE AND SONS LTD.	Dorset House, Stamford Street, London, S.E.1	Waterloo 3333
IMPERIAL CHEMICAL INDUSTRIES LTD.	Nobel House, 2 Buckingham Gate, London, S.W.1.	Victoria 4444
IMPERIAL CHEMICAL INDUSTRIES LTD. (METALS DIVISION)	Kynoch Works, Witton, Birmingham, 6	Birchfield 4848
INTEGRAL LTD.	Cousins Street, Dudley Road, Wolverhampton	Wolverhampton 24984
IRVING AIR CHUTE OF GREAT BRITAIN LTD.	Ickneild Way, Letchworth, Herts.	Letchworth 888
K.L.G. SPARKING PLUGS LTD.	Putney Vale, London, S.W.15	Putney 2671
KELVIN, BOTTOMLEY & BAIRD LTD.	Kelvin Avenue, Hillingdon, Glasgow, S.W.2	Halfway 3331
	Kelvin Works, Basingstoke	Basingstoke 690
LIGHT-METAL FORGINGS LTD.	Oldbury, Birmingham	Broadwell 1152
LODGE PLUGS LTD.	Rugby	Rugby 2076
MANGANESE BRONZE & BRASS CO. LTD., THE	Handford Works, Ipswich	Ipswich 2127
	63 Grosvenor Street, London, W.1	Mayfair 3058
MARSTON EXCELSIOR LTD.	Wolverhampton	Fordhouses (W'ton) 2181
	49/59 Armley Road, Leeds, 12	Leeds 37351 Armley 38081-5
MARTIN-BAKER AIRCRAFT CO. LTD.	Higher Denham, Bucks.	Denham 2214
MOLLART ENGINEERING CO. LTD.	Kingston By-Pass, Surbiton, Surrey	Elmbridge 3352-4
MOND NICKEL CO. LTD., THE	Sunderland House, Curzon Street, London, W.1	Grosvenor 4131
MUREX WELDING PROCESSES LTD.	Waltham Cross, Herts.	Waltham Cross 3636

DIRECTORY OF ADVERTISERS

NAPIER D., & SON LTD.	Acton, London, W.3	Shepherds Bush 1220
NORMALAIR LTD.	West Hendford, Yeovil, Somerset	Yeovil 1100
PALMER TYRE LTD., THE	Herga House, Vincent Square, London, S.W.1	Victoria 8323
PERCIVAL AIRCRAFT LTD.	Luton Airport, Luton, Beds.	Luton 2960
PETO & RADFORD	Chequers Lane, Dagenham, Essex	Rainham 34
PITMAN, SIR ISAAC & SONS LTD.	Parker Street, Kingsway, London, W.C.2	Holborn 9791
PLESSEY CO. LTD., THE	Vicarage Lane, Ilford, Essex	Ilford 3040
PULLIN, R. B., & CO. LTD.	Phoenix Works, Great West Road, Brentford, Middx.	Ealing 0011-3, 3661-3
PULSOMETER ENGINEERING CO. LTD., THE	Nine Elms Iron Works, Reading. 39 Victoria Street, London, S.W.1	Tilehurst 67182-4 Abbey 4565
QANTAS EMPIRE AIRWAYS	c/o British Overseas Airways Corporation, Airways Terminus, Buckingham Palace Road, S.W.1	Victoria 3126
ROE, A. V., & CO LTD.	Greengate, Middleton, Manchester	Failsworth 2020-2039
ROLLS-ROYCE LTD.	Derby	Derby 2424
ROTAX LTD.	Willesden Junction, London, N.W.10	Elgar 7777
ROTOL LTD.	Cheltenham Road, Gloucester	Gloucester 24431
SANGAMO WESTON LTD.	Great Cambridge Road, Enfield, Middlesex	Enfield 3434 & 1242
SAUNDERS-ROE LTD.	Head Office: Osborne, E. Cowes, Isle of Wight	Cowes 445
	London Office: 45 Parliament St., Westminster, S.W.1	Whitehall 7271
SELF-PRIMING PUMP & ENGINEERING CO. LTD.	Edinburgh Ave., Trading Estate, Slough, Bucks.	Slough 23277
SERCK RADIATORS LTD.	Warwick Road, Birmingham, 11	Victoria 0531
SHELL-MEX AND B.P. LTD.	Shell-Mex House, Strand, London, W.C.2	Temple Bar 1234
SHORT BROTHERS AND HARLAND LTD.	Seaplane Works, Queen's Island, Belfast	Belfast 58444
SKYHI LTD.	"Skyhi" Works, Worton Road, Isleworth, Middlesex	Hounslow 2211
SMITHS AIRCRAFT INSTRUMENTS LTD.	Cricklewood Works, London, N.W.3	Gladstone 3333
SOZOL (1924) LTD.	2 Copthall Buildings, London, E.C.2	Monarch 6830
SPERRY GYROSCOPE CO. LTD., THE	Great West Road, Brentford, Middlesex	Ealing 6771
STERLING METALS LTD.	Northey, Foleshill, Coventry	Coventry 89031
TEMPLE PRESS LTD.	Bowling Green Lane, London, E.C.1	Terminus 3636
UNITED STEEL COMPANIES LTD., THE	17 Westbourne Road, Sheffield, 10	Sheffield 60081
VICKERS-ARMSTRONGS LTD.	Vickers House, Broadway, Westminster, S.W.1	Abbey 7777
	Weybridge Works, Weybridge, Surrey	Byfleet 240-243
	Supermarine Works, Hursley Park, Winchester, Hants.	Chandlersford 2251
VOKES LTD.	Henley Park, near Guildford, Surrey	Guildford 62861
WAKEFIELD, C. C., & CO. LTD.	46 Grosvenor Street, London, W.1	Mayfair 9232
WELLWORTHY PISTON RINGS LTD.	Radial Works, Lymington, Hants.	Lymington 520
WESTLAND AIRCRAFT LTD.	Yeovil, Somerset	Yeovil 1100
WICKMAN, A. C., LTD.	Tile Hill, Coventry	Tile Hill 66271
WIGGIN, HENRY, & CO. LTD.	Wiggin Street, Birmingham	Edgbaston 2245
YORKSHIRE ENGINEERING SUPPLIES LTD.	Bronze Foundries, Upper Wortley Road, Leeds, 12	Leeds 38234 & 38291

The Journal is published monthly at the Offices of the Society, 4 Hamilton Place, Piccadilly, London, W1. None of the papers or paragraphs must be taken as expressing the opinion of the Council of The Royal Aeronautical Society unless such is definitely stated to be the case. Subscriptions per annum, £4 13 0 including postage: Single Numbers 7/6 or 7/9 post free. All communications for publication or Advertisements in the Journal, or on general matters affecting the Society should be addressed to—The Secretary, J. Laurence Pritchard, 4 Hamilton Place, W1. The Society's Bankers are Messrs. Coutts & Co.

Telephone: Grosvenor 3515 (5 lines). Telegraphic Address: Didaskalos, Audley, London.



C.1212-Y Mk.5
BUTTON SWITCH
For Undercarriage Retraction with Electrical Lock and Emergency Over-ride.

DOWTY
Electrical Equipment

A selection of switches representing types fitted to the following aircraft :

Airspeed *Ambassador* • Armstrong Whitworth *A.W. 52 and Apollo*
Avro *Athena and Tudor 9* • Avro Canada *C.102 and C.F.100*
Blackburn *Universal Freighter* • Bristol *Brabazon 2*
English Electric *Canberra* • Hawker *Sea Hawk*
Saunders Roe *Princess and S.R.A.1* • Short *Solent*
Vickers Armstrongs *Valetta and Varsity*
Westland *Wyvern and T.12/48 Trainer*

C.1820-Y Type
PRIMING SWITCH
for 2 or 4-engined Aircraft

C.1223-Y Type
LEVER SWITCH
for Flap, Bomb Door, Air Brake Control, etc.

C.1220-Y Type
DRUM SWITCH
for Flap, Air Brake Control, etc.

DOWTY EQUIPMENT LIMITED • CHELTENHAM

Palmer AERO TYRES

Sizes : 3·00 x 3½ tail wheel to 64 x 22·50/26" main wheel.

Treads : Smooth, patterned, ribbed, twin-contact.

Grades :

Extra Light Duty - for gliders and helicopters.

Light Duty—for small aircraft.

Heavy Duty—for medium and high performance aircraft.

Extra Heavy Duty—for multi-engined aircraft up to the largest liners.

THE PALMER TYRE LTD., EST. 1903

Tyres · Wheels · Brakes · Silvoflex Hose Units · Engineering Mechanisms

PENFOLD ST., EDGWARE RD., LONDON N.W.8

Printed by the Lewes Press (Wightman & Co. Ltd.), Friars Walk, Lewes, England, and Published by The Royal Aeronautical Society, 4 Hamilton Place, London, W.1, England.